ÁDÁM KERTÉSZ (ED.):

LANDSCAPE DEGRADATION IN HUNGARY

THEORY – METHODS – PRACTICE 74.

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Geographical Institute
Research Centre for Astronomy and Earth Sciences

Landscape Degradation in Hungary

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Contents

1. Introduction and objectives

Ádám KERTÉSZ[1]

This book gives an overview of land degradation in Hungary and contains also research results of Project No. 108 755 of the National Research, Development and Innovation Office (NKFIH), entitled: "Analysis of the natural micro-regions of Hungary from the aspect of landscape degradation." This study was supported by NKFIH and this support is gratefully acknowledged here.

Landscape degradation is one of the most urging problems of the Globe today with an ever-growing importance. The term "land degradation" has been used for several decades indicating mainly the processes of soil degradation. Landscape degradation is a broader concept than land degradation pointing to the fact that that landscape degradation means much more than just the degradation of the uppermost layer of the Earth's crust. The landscape is understood as a synthesis of landscape forming factors, therefore the decline of one or more landscape forming factors leads to the degradation of the landscape as a whole (Kertész 2009). The terms "land degradation" and "landscape degradation" will be used from now on meaning always landscape degradation.

According to Imeson (2012) roughly 20% of global land area is presumably already degraded. The consequence is a persistent decline in land productivity and of the provision of other ecosystem services. The new World Atlas of Desertification (2018) claims that over 75% of the Earth's land area is already degraded, and over 90% could become degraded by 2050. The latter seems to be an overestimation of the degraded area.

The objective of this book is to give a short overview of landscape degradation in the world as an introduction followed by the presentation of landscape degradation processes of Hungary, concentrating on the results of the above-mentioned project. The objective of the research project was to provide a survey of landscape degradation processes acting in the country as well as to investigate the sensitivity to degradation. Although the topic of the project belongs to basic research the expected results have not only theoretical but also practical relevance for policy makers at local, regional and country level.

The objective was to study altogether twelve degradation processes: (1) sheet erosion, (2) gully erosion, (3) wind erosion, (4) mass movements, (5) soil sealing, (6) landscape aesthetics, (7) salinization, (8) acidification, (9) wounds in the landscape, (10) physical degradation, (11) desertification, (12) degradation of waters. The processes will be presented in the chapters of this book illustrated with maps showing the territorial distribution of the degradation processes.

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1.1 Land and landscape degradation

There are several definitions of land degradation, emphasising various aspects of this important global process. LADA (2005) defines land degradation as the long-term reduction in the capacity of the land to perform ecosystem functions and services (including those of agro-ecosystems and urban systems) that support society and development (LADA, 2005).

Barrow (1991) defines land degradation "as the loss of utility or the reduction, loss or change of features or organisms which cannot be replaced". The land is degraded when "it suffers a loss of intrinsic qualities or a decline in its capabilities" (Blaikie, Brookfield 1987). The UNEP (1992) definition stresses the reduction of the potential of natural resources as a result of processes acting in the landscape. The role of human interventions in land degradation is emphasized in the definition of Johnson and Lewis (1995) focusing on the reduction of biological production and/or utility of an area.

The common elements in the above definitions are the reduction or loss of biological productivity and the negative effects on the functioning of the land and related ecosystems (Hudson, Alcántara-Ayala 2006). Although land degradation is originally a natural process, the role of human interventions is underlined.

Land degradation and soil degradation are very often used as synonyms because soil and land are also synonyms in the everyday colloquial language. Concerning degradation, it is evident that if the soil is degraded it has huge impacts on the landscape, because soil degradation prevents or impedes plant growth. Landscape degradation is a much broader concept than soil, or land degradation, as discussed above.

According to Lal (1993) soil degradation is a serious threat for an increasing number of areas all over the world. The degradation of the soil means the decline in soil's inherent capacity to produce economic goods and perform ecologic functions (Lal 1993).

There are numerous factors triggering landscape degradation, most of them connected with globalisation. Global processes are very much interrelated and so population growth, climate change, land use change, especially deforestation etc. are all connected with landscape degradation (see under 1.4).

Degradation processes can be of natural origin, too, but since the appearance of human beings on the Earth human-induced processes are much more important. Human interventions began with the appearance of agricultural activities, i.e. roughly 11 000 years ago. Imeson (2012) puts the beginning of human activities to 5000 years B.P. Since then the number of global population has been increasing continuously and the problems concerning population growth have become more and more serious. From the aspect of our topic, the first important point is that more people need more space. In order to gain space for agriculture, the forests are cut accompanied by the well-known problems related to soil erosion, climate change (CO_2), biodiversity loss. Mangroves are also disappearing as a consequence of the industrial activities undertaken in the sea.

The second point is that more people need more food. In order to try to fulfil this requirement more land is needed for agriculture and agriculture has to be more intensive in those areas which have good conditions for production and have been cultivated for a long time (see also 1.3). On the place of former forests the conditions for cultivation are usually bad especially in the tropics and so the soil will be damaged e.g. by erosion.

Because of the rise in the food requirement, high yield varieties are frequented requiring larger amounts of pesticides, herbicides, insecticides and other chemicals. A large proportion of these chemicals is not used by the crops but remains in the soil and will get into surface waters and in the oceans.

Growing food demand requires the extension of animal husbandry including grazing. There is not enough space to meet the grazing needs any more. The consequence is overgrazing which may lead to barren and unproductive land.

Land degradation is accompanied by a negative effect on productivity. According to Pimentel et al. (1993) soil erosion causes 15-30% less production. Nutrient depletion because of erosion leads to 29% decline of crop production and 19% loss in total production. An additional negative effect is yield reduction (e.g. yield reduction in Africa due to past soil erosion may range from 2 to 40%, with a mean loss of 8.2% for the continent (Eswaran et al. 1999). The relationship between erosion and productivity can be expressed by a negatively exponential curve, i.e. production diminishes very rapidly in the early stages of erosion. Different soil types show, of course, different patterns (Tengberg, Stocking 1997).

In addition to growing food demand the demand for industry articles, for services is increasing as well. The third point is industrial expansion and urbanisation also supporting land degradation. More and more waste accumulation also in the water bodies, especially in the oceans threaten biodiversity and lead to unexpected environmental problems. Industrialization causes air and water pollution. The chemicals especially those released by chemical industries cause the contamination of land and water. The very high and constantly increasing demand for water will be difficult to satisfy because of increasing water scarcity. The industry requires more and more energy and raw materials and leads to the exploitation of natural resources. Many of the new industry buildings, dams, energy plants lower the aesthetic value of the landscape.

1.2 Desertification

The following data were published by Research Program on Dryland Systems (2017). Drylands occupy 41% of land surface on the Globe. 30% of the world's population, 2.5 billion people live in the dry areas. The poorest and and most marginalized people in the world live in drylands, with 16% of the population living in chronic poverty. Water scarcity, frequent droughts, high climatic variability and the loss of biodiversity are characteristic in drylands. Various land degradation processes act in these regions.

Recognizing the importance of the enormous extension of drylands and the increase of dry areas on the Earth a special group of land degradation processes was defined in 1977, after a series of extremely arid periods in the Sahel. The occasion was the UNCOD (United Nations Conference on Desertification) conference in Nairobi. According to the United Nations Intergovernmental Convention to Combat Desertification "Desertification means land degradation in arid, semiarid and dry sub-humid areas resulting from various factors including climate variation and human activities" (UNCOD 1977). The threshold values of the given climatic zones are defined by the FAO-UNESCO (1977) bioclimatic index: P/ETP (precipitation/ potential evapotranspiration, see e.g. Kertész 2009). Aubreville (1949) used the term "desertification" first to describe the change of productive land into a desert. According to this concept, desertification is connected with human activities (i.e. with land mismanagement).

The UNCOD concept focuses on marginal zones surrounding the deserts, like the Sahara–Sahel marginal belt and interprets desertification as a process leading to desert development. It should be kept in mind, however, that the process of desertification may not lead to desert development, proper management can stop and may reverse the process.

There are other territories on the Earth, not only those surrounding the deserts, which correspond to the UNCOD definition and which are threatened by desertification. In Hungary the central part of the country, i.e. the Danube -Tisza Interfluve is the area with the biggest desertification risk. Drought has always been a major problem here.

As global climate change has a huge impact on desertification processes, the importance of desertification will increase and it is and it will be the most important group of land degradation processes in those regions of the world where the climate is arid, semi-arid or dry sub-humid.

1.3 Environmental degradation

As already mentioned, the concept of landscape degradation is more comprehensive, than the concept of land degradation. A new term has appeared in the last decades, i.e. the concept of environmental degradation.

According to Willow (2014) environmental degradation indicates "a decline (or series of interrelated declines) in the quality and integrity of natural resources — and therefore in the environment's ability to sustain current life conditions that is intentionally or inadvertently caused by human actions." This definition involves some ideas of sustainability, ecosystem services and landscape degradation. Willow considers environmental degradation as a profoundly political phenomenon and examines how "uninvited environmental change transforms people's understandings of and relationships to the natural world". This concept is mainly a socio-economic and sociological approach.

1.4 Landscape degradation and ecosystem services

The maintenance of the services that the ecosystems provide for human society has become a very important issue in the last few decades. Nature protection and environmental protection have already a long history starting from 1969 when NEPA (National Environmental Policy Act of the USA) was ratified, followed by the United Nations Conference on the Human Environment which was held in Stockholm in 1972.

The concept of ecosystem services dates back to the 1960s. King (1966) reports about six values associated with wildlife: commercial, recreational, biological, aesthetic, scientific and social values, mentioned by Martin-Ortega et al. (2015). Ecosystem services are in the focus of scientific research and policy making since 1997 (Costanza et al. 1997). The second important milestone was the Millennium Ecosystem Assessment (2005). Costanza et al. (1997) emphasized that: " Because ecosystem services are not fully 'captured' in commercial markets or adequately quantified in terms comparable with economic services and manufactured capital, they are often given too little weight in policy decisions. This neglect may ultimately compromise the sustainability of humans in the biosphere."

Ecosystem services are "the benefits people obtain from ecosystems." (Millennium Ecosystem Assessment, 2006). The supply and demand for ecosystem services varies geographically. The well-known publication of Constanza et al. (1997) describes the concept of ecosystem services and natural capital. Both terms express that nature itself provides valuable goods and services to human society, and it is very clear that our well-being depends on the protection of nature.

Ecosystem services are divided in four groups. (1) Supporting services provide the basic conditions for life (e.g., primary production, fertile soils). 30-50% of primary production is consumed by humans, mainly by agriculture and forestry and the rate is growing (Foley et al. 2005). (2) Regulating services assure the functioning of ecosystems (e.g. flood and decease control, pollination). (3) Supporting services belong to the third group (e.g. food, fuel, wood) and (4) the cultural services include e.g. cultural and recreational benefits.

According to The Global Land Outlook a significant proportion of managed and natural ecosystems are degrading: over the last two decades, approximately 20% of the Earth's vegetated surface shows persistent declining trends in productivity, mainly as a result of land/water use and management practices (UNCCD 2017).

Considering a very important supporting service, food for a very quickly growing population there are two ways of trying to satisfy this demand: one way is the intensification of agriculture in already used areas disposing of good conditions. A more intensive agriculture may cause more serious land degradation problems. The other solution is to involve new areas for agricultural use. This can be achieved by deforestation or by using some of those fields which were not yet used for agriculture because of unfavourable conditions.

Future land degradation will be, of course, different in various parts of the world. According to Crosson (1997) an accelerating rate of degradation (0.4%) can be assumed for the coming 30 years, accompanied by a decline of altogether 17% of agricultural activity. Land degradation will not be a serious threat to food supply because this supply will come from the non-degrading lands.

1.5 Land degradation and global change

As already mentioned, the processes of global environmental change are strongly connected to each other and this is true for the processes of landscape degradation, too. The human society plays a decisive role in global environmental change, especially since the beginning of the industrial revolution.

The first and probably the most important process is the exponential increase of population and as a result of this the number of people living on the Earth is 7.7 billion in 2019 and will be 10 billion by 2050. Urban population is 55% of the total world population (World population 2019). As it is well known, the growing rate of the developing countries is much higher than that of the developed countries, but the average growing rate is declining. In 2018-2019 the value of the growing rate is 1.07% whereas it was 1.09 in 2017 (World population 2019). The distribution of the population among the continents is the following: Asia 59.4%, Africa 17.1%, Europe 9.6%, Latin America and the Caribbean 8.5%, North America 4.8% and Oceania 0.5%. The proportion of developing world is 85.6%. The consequence is as simple as that: more people, more degradation. The expansion of cities, industry plants, roads etc. leads to the increase of the sealed area, water and air pollution, a growing amount of waste etc. As already mentioned, the growing population will need more food, fiber, water, energy etc. In order to get new areas for cultivation, the present land use has to be changed and cultivation has to be more intensive in the areas with the best conditions, leading to landscape degradation, as already indicated in Chapters 1.1 and 1.3. The conditions for an acceptable life are worse and worse so that migration from these countries is already present and will grow constantly in the future.

Global climate change is due to human-released greenhouse gases originating from emissions associated with energy use, but on local and regional scales, urbanization and land use changes play also an important role. The IPCC Special Report (IPCC 2018) informs about the impacts of global warming of 1.5 °C above pre-industrial levels. Climate models project big differences in regional climate characteristics between present-day and global warming of 1.5 °C, and between 1.5 °C and 2 °C.

The differences are as follows: increases in mean temperature in most land and ocean regions (high confidence), hot extremes in most inhabited regions (high confidence), heavy precipitation in several regions (medium confidence), and the probability of drought and precipitation deficits in some regions (medium confidence) (IPCC 2018). Increasing drought intensity and frequency as well as the increase of high intensity rainfall events, i.e. increases in frequency, intensity, and/or amount of heavy precipitation and other climate and weather extremes point to the possible acceleration of degradation processes in some regions of the Earth. Risks from droughts and precipitation deficits are projected to be higher at 2 °C compared to 1.5 °C of global warming in some regions (medium confidence, IPCC 2018). Climate change is a major factor influencing desertification processes, the global importance of desertification will grow.

Land use change is also a very important process of global environmental change. Land use/land cover changes are responsible for 35% of human-induced CO_2 equivalents (Foley et al. 2005) pointing to the relationship with climate change. As already discussed, new fields for agricultural production are needed and are in most cases on the place of former forests. If the forest is cut land degradation will take place. In addition to the increase of areas used for agriculture, urban and industrial areas are growing, too. Urban intensification is accompanied by large increases in resource consumption, habitat fragmentation and biodiversity loss (Foley et al. 2005, 2014; Kertész et al. 2019). Land use changes are always accompanied by conflicts including the contradiction between agricultural land use and nature conservation, the extension of urban areas and the decrease of green, natural and semi-natural areas. If renewable energy plants are constructed, they ruin the aesthetical value of the landscape.

1.6 Landscape degradation and policy making

For the successful implementation of sustainable development goals (SDG) the application of Integrated Landscape Management (ILM) is needed.

According to the definition of Scherr et al. (2013): "Integrated landscape management (ILM) refers to long term collaboration among different groups of stakeholders to achieve the multiple objectives required from the landscape, such as agricultural production, the delivery of ecosystem services, cultural heritage and values, and rural livelihoods, to name but a few." ILM is related to the integration across sectors and scales and to increasing coordination, harmonization of planning, implementation and monitoring processes at the landscape, sub-national and national, regional and global levels. The emphasis is on coordination and cooperation at different government levels, communities, businesses and civil societies. ILM can lead to cost efficiencies at multiple levels (Thaxton et al. 2017).

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2. Sheet erosion

Csaba CENTERI[1], Gergely JAKAB[2], Ádám KERTÉSZ[2]

2.1 Introduction

Soil erosion is the most important land degradation process in agricultural areas. The soil is a very significant natural resource in Hungary, therefore the study of soil erosion is fundamental in order to provide suitable conservation measures against soil erosion. Soil erosion is caused either by water or by wind. Water erosion processes include sheet and gully erosion. They will be dealt with separately in the coming chapters.

2.3 million hectares are affected by water erosion (13.2% slightly, 13.6% moderately and 8.5% severely eroded) and 1.5 million hectares by wind erosion (Stefanovits, Várallyay 1992, see Table 1 and Figures 1 and 2).

2.2 Research on sheet erosion in Hungary

Wind erosion research is presented in chapter 4.3, gully erosion research is shown in chapter 3.2. A short review of research activities on soil erosion by water is given below. The map shown in Figure 1 (Stefanovits, Duck 1964) is the first milestone of soil erosion research (see also 2.5), followed by studies restricted to smaller areas, hillslopes or small catchments (e.g. Erődi et al. 1965, Dezsény 1982, Csepinszky, Jakab 1999, Máté 1974, Krisztián 1998, Góczán et al. 1973, Kertész, Góczán 1988, Kertész et al. 2001, Kerényi 1991, Mezősi, Szatmári 1996).

The second milestone is the study of soil erosion and eutrophication problems of Lake Balaton catchment by the Geographical Research Institute of the Hungarian Academy of Sciences, see e.g. Kertész et al. (1995). Modelling studies were performed in the Tetves catchment (subcatchment of Lake Balaton) applying the USLE, EPIC and MEDRUSH models (Kertész et al. 2001, Kertész et al. 2002.) as well as in the catchment of Lake Velence (604 km^2). Research on soil erosion is ongoing. The results include the application of a self-constructed rainfall simulator (Keller et al. 2018.) and the comparison of conventional and conventional tillage also form the aspect of soil erosion (see e.g. Madarász et al. 2016)

A soil loss prediction map was prepared by the Department of Soil Science and Agricultural Chemistry, Szent István University, Gödöllő (1:50 000) for the Northern catchment of Lake Balaton. The Department of Landscape Ecology performed rainfall simulation experiments on seven soil types of Lake Balaton Watershed in cooperation with

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*Table 1. Soil erosion in Hungary (*Stefanovits, Várallyay 1992*)*

	Thousand hectares	% of the total area	% of the agricultural land	% of the eroded land
Area of the country	9303	100.0	-	-
Area of agricultural land	6484	69.7	100.0	-
Arable land	4713	50.7	73.0	-
Total eroded land	2297	24.7	35.3	100.0
strongly	554	6.0	8.5	24.1
moderately	885	9.5	13.6	38.5
weekly	852	9.2	13.2	37.4

the Department of Soil Science and Water Management, Keszthely (Veszprém University), to determine the K factor of the USLE (Centeri 2002). This department carried out significant research by their own rainfall simulator. The simulator was used in several scientific co-operations as well (see e.g. Kertész et al. 2002). The Institute for Soil Sciences and Agrochemistry, Hungarian Academy of Sciences prepared soil erosion maps (Pásztor et al. 2015). The Department of Physical Geography and Geoinformatics, University of Szeged, was also active in this field (see e.g. Farsang et al. 2004).

2.3 Soil erosion in Hungary

From the aspect of soil erosion, Hungary belongs to the countries with medium risk. The amount of the eroded soil is remarkable but as it is well known most of it will be accumulated on the slope and so the damage caused by erosion is difficult

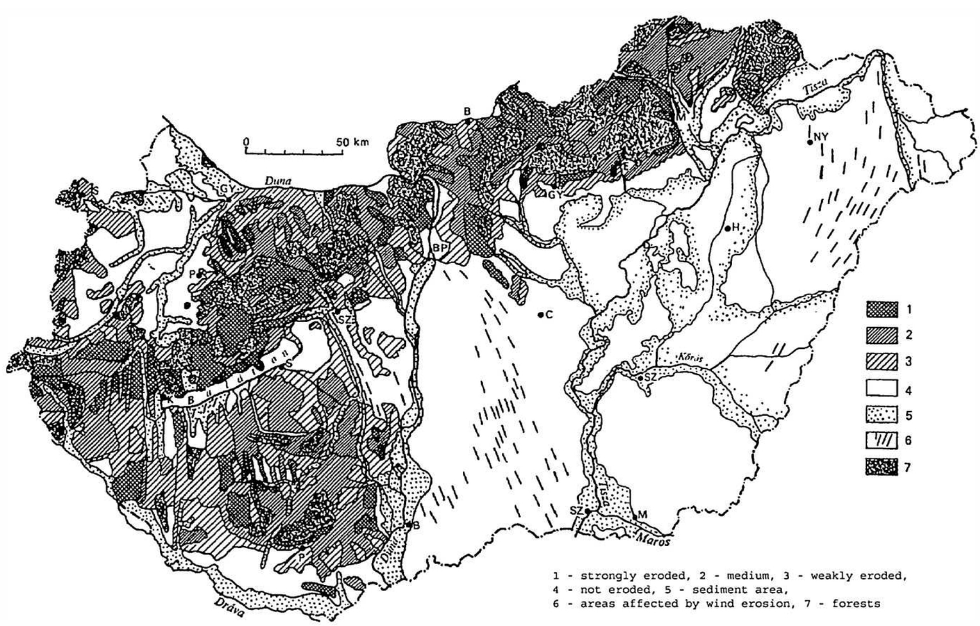

Fig. 1. Soil erosion in Hungary (Stefanovits, Várallyay 1992)

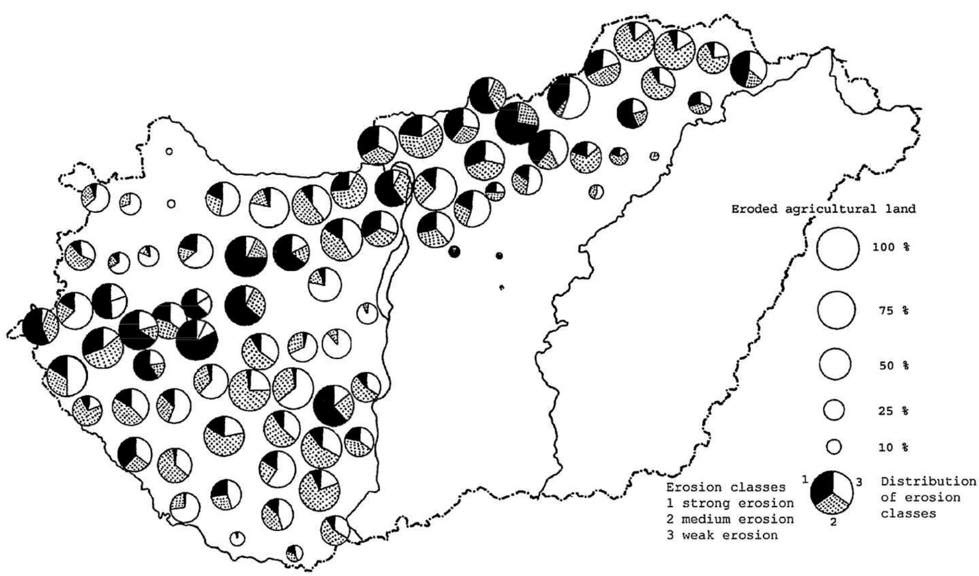

Fig. 2. Distribution of eroded agricultural land in the hilly administrative regions of Hungary (Stefanovits, Várallyay 1992)

to quantify.

Relief and drainage conditions of Hungary provide appropriate preconditions for water-erosion processes in the mountain and hilly regions where surplus runoff, the loss of soil, nutrients and fertilizers and the accumulation of the washed-down material present serious problems. Moderate and strong water and wind erosion processes operate on more than 1.7 million hectares.

2.4 Environmental conditions of sheet erosion

a) Soil parent material

Easily attackable unconsolidated sediments, including mainly loess and loess like sediments cover roughly two thirds of the country area. Other Quaternary deposits including sand, clay and gravel are also important.

b) Precipitation

Mean annual precipitation varies bet-

Table 2. Land use changes in Hungary, 1895-2018 (1000 ha)

Year	Arable land	Gardens orchards	Vineyards	Meadows	Pastures	Agricult. land	Forests	Reed	Cult. area	Non-cult. area
1895	5103	95	175	798	1268	7439	1191	49	8678	528
1930	5587	107	214	668	1001	7577	1095	30	8702	595
1945	5567	115	215	639	962	7498	1116	29	8643	650
1950	5518	152	230	609	865	7376	1166	29	8571	728
1965	5085	319	247	419	885	6954	1422	29	8404	900
1970	5046	318	230	407	876	6875	1471	32	8378	925
2001	4516	195	93	1061		5865	1772	60	7697	1606
2018	4334	139	73	799		5344	940	36	7356	1948

Table 3. Changes of agricultural land use in Hungary (% of total area)

	1938	1960	1985	1993	2001	2018
Arable land	60.4	57.1	50.4	50.7	48.5	46.60
Gardens/orchards	1.3	2.0	4.8	1.4	2.1	1.51
Vineyards	2.2	2.2	1.7	1.4	1.0	0.79
Meadows/pastures	17.3	15.4	13.6	12.4	11.4	8.64
Agricultural land	81.2	76.7	70.5	65.9	63.0	57.53

ween less than 500 mm and more than 900 mm. The central part of the country, the Danube-Tisza Interfluve is the driest and the western part of the country as well as the highest mountain peaks are the wettest. Maximum precipitation is in June and the second maximum may occur in October. Drought and high intensity rainfalls are typical during the summer. High intensity rainfalls trigger the biggest erosion events on hillslopes.

c) Land use

Changes of land use over more than 100 years are presented in Table 2 and Table 3. The area used for agriculture has been diminishing continuously since 1945 and the same is true for arable land, vineyards etc. The percentage of agricultural land in 2018 was only 57.53% compared to 81.2% in 1938. Forested area increased form 12.5% in 1945 to 20.85% in 2018.

Considering land use changes from the aspect of soil erosion the increase of forests and the decrease of agricultural area are favourable changes. The huge arable fields established in 1960 when collectivization started and the extension of arable land to the hillslopes are disadvantageous factors of soil erosion.

2.5 Soil erosion mapping

It is hardly possible to map the present state of erosion because it changes from one moment to the other. Areas eroded to bedrock extend after every high intensity rainfall if the surface is not covered by vegetation, i.e. after harvest, more or less during summertime. Soil erosion maps compiled during the last 5-6 decades present actually soil erosion sensitivity. The given soil loss values indicate the degree of erosion so that in reality it is a degree on a scale between slight and strong erosion which is behind the values given as soil loss t ha^{-1}. Figures 1, 3, 4 and 5 are based on the expected value of soil loss and they identify actually the degree of soil erosion risk/endangerment/vulnerability.

The current state of soil erosion can be determined on the basis of remote sensing materials, air and satellite images as it is subject to continuous change. The map of the current state of erosion would be similar to the map of erosion risk. The reason for that is twofold. On one hand, the eroded areas where a considerable part of the soil profile is missing have a low resistance against erosion so that they would be further eroded very easily. On the other hand, steep slopes belong always to the category of the highest risk.

It is important to mention that besides soil loss caused by erosion, soil formation takes place as well. Soil formation depends on many environmental factors and its rate is different in time and space. There are no measurement data about it. The rate is assessed as less than 1 mm in 10-50 years and this rate is much less than the rate of soil loss by erosion.

The first soil erosion map of the country was compiled in 1964 by Stefanovits and Duck, covering, however, only improved farmland (excluding non-agricultural uses, e.g. forests, urban and industrial areas, roads, etc.). The map on Figure 1 is also based on this map. The analysis of

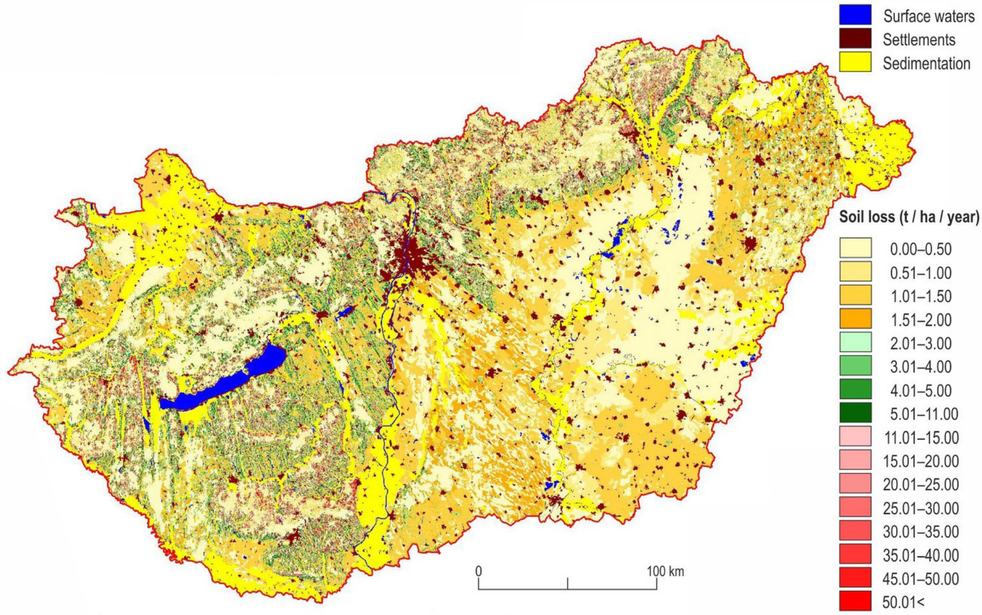

Fig. 3. Soil loss assessment with the USLE for Hungary

soil profiles provided the mapping basis. First a soil profile not affected by soil erosion had to be found which was used as a basis for comparison in characterizing the soil profiles of the neighbouring area. Three stages of erosion were defined: slightly eroded if 70% of the basic profile can be detected. A soil is medium eroded if 30-70% and strongly eroded if less than 30% of the basic profile is available. The compared soils are supposed to have the same bedrock and the same particle-size distribution as the basic profile. Areas affected by wind erosion are also represented on the map.

The area affected by soil erosion has been estimated by many authors. According to Erődi et al. (1965), the annual rate of erosion comes to about 50 million m^3 whilst some soil scientists calculate a soil erosion of 90-100 million m^3y^{-1}. In the hilly areas the averages rate of erosion is about 50 t $ha^{-1}y^{-1}$ which is the equivalent of a yearly erosion of 1 mm.

Sheet erosion risk is related to human intervention, especially to arable cultivation. As already mentioned, the eroded soil will be transported only to short distances and will be deposited within the field, on the slope. The role of scale is very important when evaluating erodibility and erosion risk. It is difficult to show the details of erosion risk at country scale, in small scale.

Empirical and physical models are applied used for the assessment of the expected value of soil loss cause by sheet erosion. There are several models for soil erosion assessment. The USLE model (1) was applied for the map presented in Figure 3 using GIS ArcView (Kertész, Centeri 2006).

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \qquad (1)$$

A = soil loss (t ha^{-1})

R = the rainfall erosion index (MJ mm $ha^{-1}h^{-1}y^{-1}$) was based on the rainfall erosivity map of Thyll (1992);

K = Soil Erodibility Factor (t ha h ha^{-1} MJ^{-1} mm^{-1}) data taken from the digital version of the Hungarian Soil Map

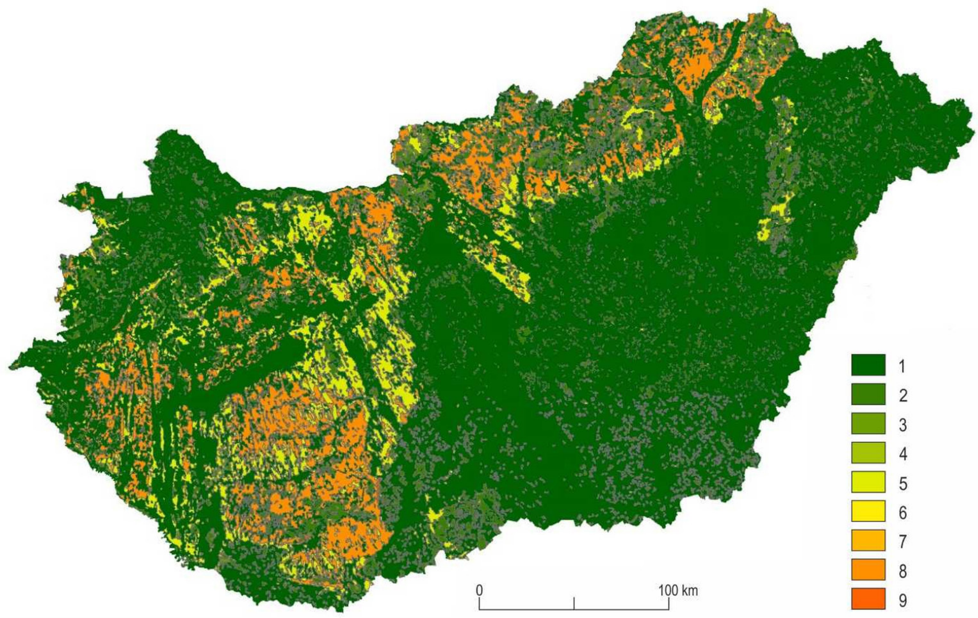

Fig. 4. Soil erosion risk map of Hungary (Pásztor et al. 2015). The legend categories (1-9) correspond to the following t ha^{-1} values: 1 = 0.0–0.5, 2 = 0.5–1.0, 3 = 1.0–1.5, 4 = 1.5–2.0, 5 = 2.0–5.0, 6 = 5.0–8.0, 7 = 8.0–11.0, 8 = 11.0–100.0, 9 = > 100.0

1:100 000 (Institute for Soil Sciences and Agrochemistry, Hungarian Academy of Sciences) and the estimation of K factors is calculated from rainfall simulation data);

L = Slope Length (dimensionless) and S = Slope Gradient Factor (dimensionless) from the modified version (Pataki 2000) of slope length calculation of Hickey et al. (1994) using the contour lines and altitude data for the 1:100 000 scale topographic map of Hungary);

C = Cropping Cover Management Factor (dimensionless), from the CORINE Land Cover 100;

P = Agricultural Practice Factor (dimensionless) not determined, =1.

As already mentioned, sedimentation/accumulation is difficult to quantify not even the USLE is capable of that. If the soil properties indicated sedimentation the K value was set to 0 to show these soil types as potential sedimentation areas.

The most recent soil erosion map was prepared in the Institute for Soil Sciences and Agricultural Chemistry, Hungarian Academy of Sciences by Pásztor et al. (2015, Figure 4). In Hungary there is a strong relationship between relief and soil loss. This can be seen on all soil erosion maps including the most recent map. Strongly eroded areas are in the mountains, especially in the piedmont area and in the hilly countries. As shown above, slope gradient doesn't play a decisive role in sheet erosion, the main driving factors are soil parent material and land use. The high proportion of arable fields is an important risk factor. Fields are without vegetation cover for a long period after harvest and there is no protection against the eroding activity of rainfall as discussed above.

ESDAC (The European Soil Data Centre) published among others datasets of Soil Threat Data including the maps of the factors of the USLE, i.e. maps of the LS factor, P-factor, K-factor, R-factor, C-factor for Europe. The K-factor map is shown in Figure 5. The calculation of soil erodibility

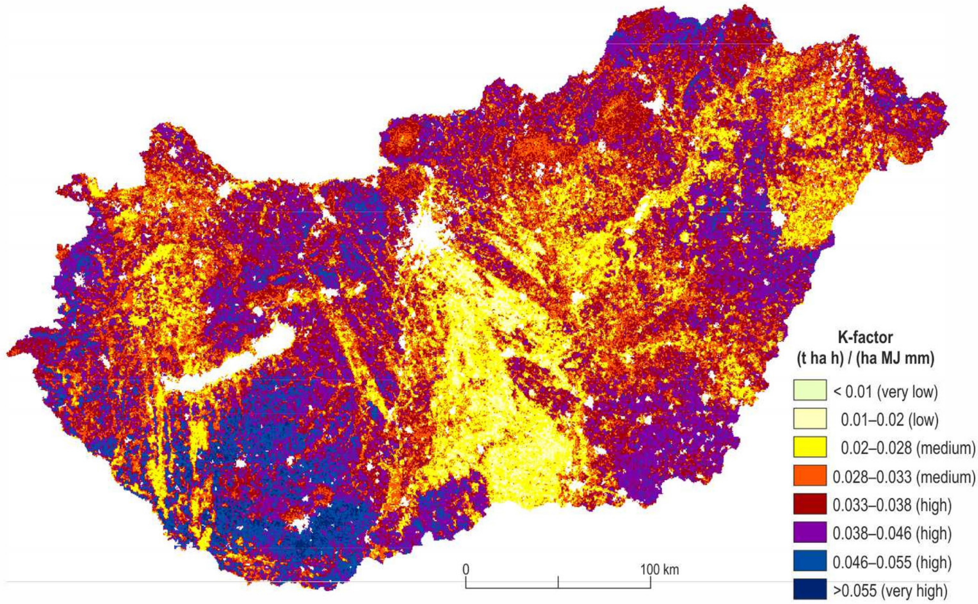

Fig. 5. K-factor map of Hungary (European Commission, Joint Research Centre, 2014)

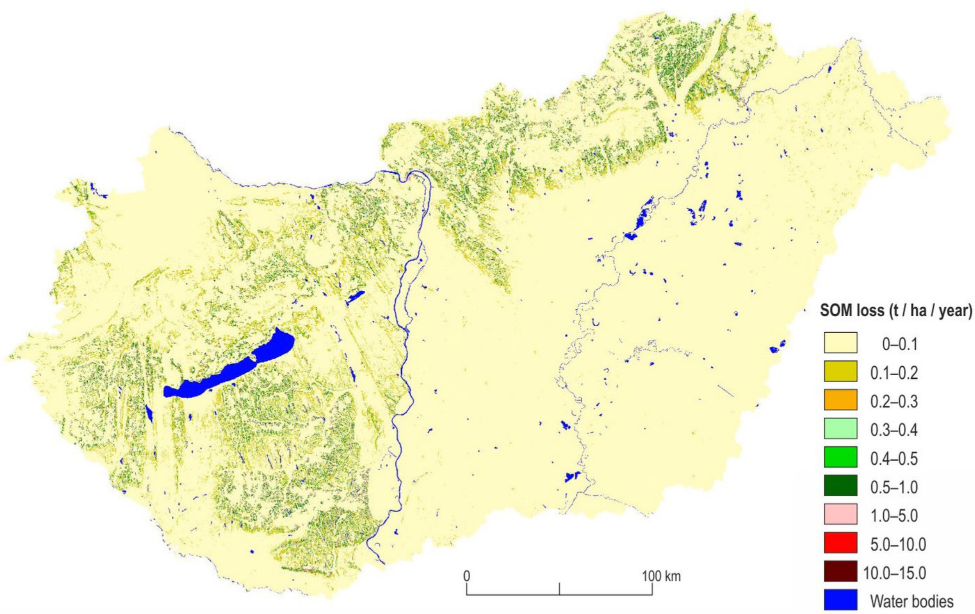

Fig. 6. Soil organic matter loss of Hungary due to water erosion based on the estimated soil loss by the USLE and the soil organic matter content of the upper soil layer

is based on the nomograph of Wischmeier and Smith (1978). The mean K-factor for Europe was estimated at 0.032 t ha h ha^{-1} MJ^{-1} mm^{-1} with a standard deviation of 0.009 t ha h ha^{-1} MJ^{-1} mm^{-1}. The resolution of the dataset is 500 m (high resolution dataset). The range of values is 0.004 – 0.076 t ha h ha^{-1} MJ^{-1} mm^{-1} (Panagos et al. 2014). There is a good correspondece between the loess map of Europe and the spatial pattern of the areas with high soil erodibility. The estimation of the average K-factor values of the European loess areas is 0.0419 t ha h ha^{-1} MJ^{-1} mm^{-1} (Panagos et al. 2014).

Obviously soil erosion leads to soil organic matter loss, or at least to the redistribution of organic matter (Szalai et al. 2016). The map below (Figure 6) shows the organic matter loss due to soil erosion.

The soil organic matter loss is basically below 0.2 t $ha^{-1}y^{-1}$ for the majority of Hungary as the amount of soil loss is below 11 t $ha^{-1}y^{-1}$. The soil organic matter loss is negligible all over the lowlands and on the steepest areas, the former is flat, the latter is covered by forests. The biggest amount of soil loss is on the hilly areas where slope steepness is high and are under arable land use. Soil protection measures are normally missing, we can find areas with these measures only under vineyards and orchards. The map provides hotspots where measures against soil organic matter loss should be introduced.

2.6 Conclusions

The above maps provide a good basis for soil erosion risk assessment drawing our attention to the importance of soil conservation measures. Erosion control is a principal task of farming on hillslopes. The techniques applied are usually grouped as either agro-technological, biological or technical.

The most common mechanical soil conservation practices are: ridging (ridges are obliterated when ploughing on slopes <12% and maintained on 12-17% slopes) and terracing of 17-25% slopes. Both types of erosion control are usually supplemented with grass waterways. Where runoff surges are particulary destructive, waterways are built of more durable materials.

Some of the above conservation techniques are expensive and time-consuming. They are, however, important and there is an urging need for their application. Simple and less expensive methods include land use and crop-rotation planning, preservation of the natural elements of the landscape which reduce or event prevent overland flow and erosion, and agronomic techniques (e.g. subsoiling and ribbed rolling). They promote the infiltration of rainwater into the soil.

One of the best ways is the introduction of conservation agriculture. Conventional agriculture is based on tillage and it causes severe land degradation problems, including soil erosion and pollution and other environmental damage, i.e. it decreases biodiversity and wildlife, it is accompanied by low energy efficiency and it makes an important contribution to global climate change. Conservation tillage has many benefits for the soil and for the environment because the soil will be preserved in semi-natural conditions as soil disturbance by cultivation is minimized and physical and chemical depletion is reduced. The benefits will not be analyzed here only in relation to soil erosion. When CT is applied, crop residues remain on the soil surface offering very good protection against erosion (Kertész et al. 2011).

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3. Gully erosion

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3.1 Introduction

A few decades ago soil erosion research concentrated on sheet erosion. From the 1980s the eroding, transporting and relief forming effect of gully erosion was recognized and it became clear that gully erosion may be more destructive than sheet erosion. The importance of gully erosion in arid and semi-arid areas was well known, whilst in humid and sub-humid regions the important role of gully erosion has only been recognized recently (Poesen et al. 1996).

Gully erosion generates 20–30 cm to 20 m deep gullies (Bergsma 1996). There are different views about the proportion of gully erosion in the total amount of soil loss, our experiences show that gully erosion processes have a bigger share than those of sheet erosion (Jakab et al. 2006).

Poesen et al. (2003) define gully erosion "as the erosion process whereby runoff water accumulates and often recurs in narrow channels and, over short periods, removes the soil from this narrow area to considerable depths".

Various gully types (permanent, ephemeral and bank gullies) develop under different climatic conditions and various land use types. The Hungarian term does not suggest the size of gully erosion forms whereas the English expression suggests a relatively big cut in the surface. Microrill, rill and gully erosion all belong to the group of linear erosion processes. Gully erosion is the worldwide used term, therefore, this term will be used below.

The kinetic energy of concentrated surface flow enable the water to cut into the surface and the result is a gully erosion form. The rill, or gully will transport a considerable amount of soil, not only from the gully itself, but also from the catchment of the gully and so it transports the sediments removed by sheet erosion as well. Gully erosion plays a decisive role in the redistribution of eroded soil on a slope and in delivering it to watercourses (Evans 1993, cited by Poesen et al. 2003).

Without the presence of gullies runoff water and sediments would not be able to be transported far whereas they can cover much longer distances when transported in a gully. It is evident that a slope is needed for gully formation, there is no evident relationship between slope gradient and gully size and the number of gullies developed on the given slope. Runoff amount controls gully size and the number of gullies. If the surface is covered by vegetation, or litter runoff development will hardly be possible and without it the formation of rills and gullies will hardly be possible. Without vegetation cover a surface crust development will take place reducing infiltration and increasing

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runoff. Since there is no protection against erosion, gullies may develop even on slopes with a slight gradient, especially on arable land. During the last centuries agriculture has been extending to areas covered by natural vegetation, mainly by forest before. Deforestation is a harmful process in itself and it can be a triggering factor of gully erosion, too.

3.2 Research activities on gully erosion

Stefanovits, Várallyay (1992) reported on a gully erosion survey carried out for the characterization of gully erosion according to the length of gullies in a given survey area. The following categories were suggested: a) weakly gullied area: <200 m/km^2 gullies; b) moderately gullied area: 200–500 m/km^2; c) strongly gullied area: >500 m/km^2. Thyll (1992) proposed a method based on the classification of soil loss values determined on a 40x40 m test area to give gully erosion rate: weak (<40 t ha^{-1}), medium (40–100 t ha^{-1}) and strong (>100 t ha^{-1}) gully erosion.

Pécsi (1955) reported on gullies in the Danube valley, Pinczés (1968, 1980) investigated the gullies of the Tokaj Hill. Boros (1977) carried out research on gully erosion mapping and on gully morphometry. Pannonian sediments and loess are liable for the development of rills and gullies (Kádár 1954; Ádám 1969). The hilly countries of southern Transdanubia were studied by Ádám (1969). Kerényi, Kocsisné Hodosi (1990) investigated the gully erosion forms in vineyards covered by loess. There are also some publications on piping (Kádár 1954; Ádám 1969; Kerényi and Kocsisné Hodosi 1990).

Research on gully development Lake Balaton catchment was carried out by several authors. Tóth (2004) analysed the ratio of sheet and gully erosion in the Tetves catchment. Jakab et al. (2005) made a very detailed morphometrical survey of gullies in the same catchment (Kertész, Jakab 2011). Kertész (2004) studied geomorphic processes on collapsible and dispersive soils. Results based on rainfall simulation experiments on gully initiation and development were published by Csepinszky et al. 1998; Csepinszky, Jakab 1999; Sisák et al. 2002; Centeri 2002; Centeri, Pataki, 2003, 2005; Szűcs et al. 2006; Jakab, Szalai 2005; Balogh et al. 2008.

3.3 Triggering factors of gully erosion

a) Soil parent material is a decisive factor of soil surface erodibility. Two thirds of the total area of Hungary are covered by loose sediments like loess and loess like deposits, susceptible to soil erosion and mass movement processes in the hilly regions of Hungary. Cultivated hillslopes are especially prone to soil erosion. Although the best conditions for gully erosion are given in the areas covered by a thick loess cover, Pannonian sands favour gully erosion as well.

Gully initiation and development are promoted also by subsurface erosion, i.e. by piping. Physical and chemical properties of loess and loess-like sediments offer favourable conditions for the development of pipes. The calcium carbonate content (including lime concretions in older loess deposits) offers good conditions for collapsibility, together with the very high porosity (volume of pores is 40-60%) of these deposits. Sheet erosion, rill erosion, gully erosion, piping (tunnel erosion, suberosion), wind erosion and mass movements are the most important processes on collapsible/dispersive rocks and soils.

b) Rainfall amount and intensity are the triggering factors of erosion. Stefanovits, Várallyay (1992) identified the so called „erosion-sensitive days" characterized by >30 mm daily rainfall are of crucial importance which may occur 4-12-times per year in Hungary. The most informative value is the rainfall threshold leading to the development of gullies in various environments. According to Poesen et al. (2003) there is not much difference in threshold rains of rills and gullies. Extreme events leading to higher gully erosion risk will be more frequent as a consequence of global climate change. Long periods of drought will alternate with storms during the summer months.

c) Land use is another important factor of gully development. There is a huge number of studies on the effect of land use on gully development. Gábris et al. (2003) reported on intensive gully erosion activities in the nineteenth century as a consequence of deforestation followed by arable farming in loess covered areas of NE Hungary. The most effective and efficient measure to stop gully development is the extension of forested areas (Romanescu, Nicu 2014).

3.4 Gully database of Hungary

The database contains gullies according to gully length. No distinction is made between shallow and deep gullies. (A gully may be only 0.5 m, or 15 m deep). The map was prepared by digitizing of 1:10 000 topographic maps, i.e. it shows a snapshot of gullies. It is difficult to interpret the map because the very high gully distribution values in the forests of the mountains developed during a long period of time, several thousand years, whereas the rills and gullies on arable land will be labelled by each cultivation operation. Ephemeral gullies are difficult to survey and the contradiction is that the sediment transported in the gullies plays the most important role in recent soil erosion on hillslopes. The high gully density values of the forested areas shown on the map reflect intensive soil erosion of

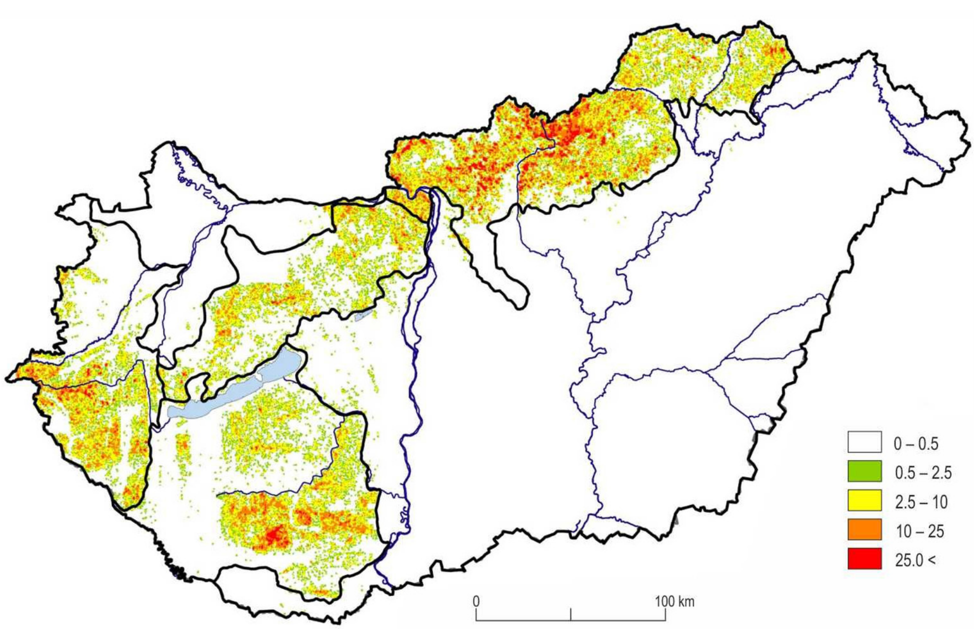

Fig. 1. Gully dissection map of Hungary (km km^{-2})

Table 1. Gully density in Hungary

Gully density km km^{-2}	Area km^2	Percentage of country area %
0–0.5	75 359	81
0.5–2.5	5 625	6
2.5–10	7 539	8
10–25	3 314	4
25<	644	1

former times and it doesn't mean a high erosion risk today. Gully erosion forms leading to serious damages on hillslopes cannot be included in the database and therefore cannot be presented on the map because of the reasons described above.

The evaluation of the map shown in Figure 1 is presented in Table 2. The overwhelming part of gully density data belong to the categories <2.5 m km^2. 0.7% of the country area is included in the highest category of >25 m km^2 (Figure 1). This value seems to be very small but we should keep in mind that roughly two thirds of the territory of Hungary are lowland where gully density was not surveyed and so the significance of this relatively small value will be higher.

The analysis of the relationship between gully distribution and the driving factors show that the main driving factor of gully development is relief followed by soil parent material. The role of soil types and land use is less important because these variables are not independent form relief.

Gully length is affected mainly by soil parent material. Longer gullies develop on loose, porous sediments rather than on compact rocks. The smallest median value is in the North Hungarian Range where the dissection index reaches the highest values, i.e. short gullies are typical here opposed to the bifurcating, complex gully systems of the Transdanubian Range.

Most of the micro-regions shown in Table 4 are in the North Hungarian Range whereas there is only one micro-region in the Transdanubian Hills, however, with an outstanding territorial extension. Surprisingly there are no high values in the Transdanubian Range.

There are 112 000 gullies with a total length of over 22 000 km included in the database. The total length of the longest gully system is 22 km. This is an outstanding value, the following value is

*Table 2. Gully characteristics of the natural macro-regions of Hungary**

	TH	TR	NR	EAF	Country
Area (km^2)	11 969	6 470	10 971	7 330	93 036
Number of gullies	22 903	11 131	54 994	21 642	111 936
Total gully length (km)	4 956	2 386	10 618	3 910	22 079
Average length (m)	216	214	193	181	197
Standard deviation(m)	359	314	382	305	355.3
Median (m)	124	121	90	97	112
Maximum (km)	22.1	6.5	9.7	8.7	22.1
Dissection (km km^{-2})	0.41	0.37	0.97	0.53	0.24
Average slope gradient (%)**	2.6	2.4	3	2.2	2.7

*TH = Transdanubian Hills, TR = Transdanubian Range, NR = North Hungarian Range, EAF = Eastern Alpine Foreland. **Slope categories: 1 = 0-5%, 2 = 5 – 12%, 3 = 12-17%, 4 = 17-25%, 5 = 25%<

Table 3. Gully density characteristics of the natural micro-regions most endangered by gully erosion

	Börzsöny	Zselic	Medves	Felső-Tarna Hills
Number of gullies	2 260	6 579	1 979	3 105
Dissection index (km km^{-2})	1.43	1.45	3.595	4.355
Total gully length (m)	638 309	1 693 374	464 769	624 948
Average gully length (m)	282	258	243	201
Minimum gully length (m)	2	2	12	1
Maximum gully length (m)	7 308	16 220	6 996	6 218
Mean value (m)	126	133	79	81

under 10 km. The average gully length in the country is 200 m. There are differences between the natural macro-regions with the highest values in the Transdanubian Range and in the Transdanubian Hills (Table 3), so that no direct relationship exists between gully length and gradient.

Land use distribution at the time of surveying is presented in Table 5. Surprisingly the proportion of gullies on arable land is the smallest in the Transdanubian Hills in spite of the fact that the share of arable land in this micro region is very high. A possible explanation for this is that the gullies will be let to be afforested sooner than in the mountains where the proportion of arable land is very little.

The most dissected areas are in the forests. It is important to mention that the ephemeral gullies on arable land are rarely shown on the maps included in the database. Concerning soil value the conclusion is that gullies develop on medium quality soils and they can hardly be found on low quality soils as these are mostly sandy territories where the water will infiltrate into the soil and the conditions for gully development are not provided.

Land use types characteristic for gully development at the time of the preparation of the topographic map in 1971 and those of the CORINE 2000 database were compared on country level and on the level of macro-regions. It can be asserted the proportion of gullies in the forest diminished as a result of deforestation. It should be noted that gullies tighter than 50 m were presented in the CORINE database and consequently the gullies with widths < 50 m and forested since 1971 were not included in the database although their vertical extension may be significant. We can see that the proportion of gullies on cultivated areas of the North Hungarian Range decreased as the areas with the worst conditions are utilized for meadow and pasture now and not as arable land any more.

It is repeatedly emphasized that only bigger, permanent gullies shown on topographic maps are included in the gully cadastre and the smaller ephemeral gullies typical on cropland not necessarily, in spite of their decisive role in soil erosion.

Table 4. Gully distribution according to land use in the1970s in %

	TH	TR	NR	EAF
Forest	90	72	87	78
Pasture	4	7	1	7
Arable land, orchard	6	21	12	15

Note : For abbreviations TH, TR, NR and EAF see *Table 2.*

3.5 Gully erosion risk

The relationship between two most important factors of gully development and the most endangered areas (the upper two categories on Figure 1) was investigated from the aspect of gully erosion risk. The first factor is gradient and the second is land use/land cover. The values of the CORINE land cover database were classified into six categories. Comparing slope gradient and gully density an interesting observation can be made, i.e. gullies do not develop on the steepest slopes. There are not too many gullies in the central regions of Hungarian mountains despite of their steep slopes. It should be taken into account that these areas are mostly covered by forests. Nevertheless, the marginal, piedmont regions of the mountains are rich in gullies.

Concerning natural mesoregions, the Cserhát, Mátra, Börzsöny mountains, the North Hungarian basins, in Transdanubia the Baranya-Tolna Hills, Zala Hills and the Eastern Alpine Foreland are the most endangered regions. The most endangered micro-regions belong to the above mentioned macro regions (Medves, Karancs, Western Mátra and Mátra Foothills.

It is important to keep in mind that the gullies included in the inventory are of various origins. Part of them has probably existed for a longer time, their development is not related to present climatic, relief land use and soil and to other environmental conditions. These gullies were formed on compact rocks and they are therefore stable and will exist probably for a long time in the future. As for their future development, presumably no significant increase can be expected in the future.

Gullies cut into porous rocks belong to another group. They are characteristic of the areas covered by loess and loess-like sediments. They may exist for several hundreds of years. On the other hand, their formation is relatively quick if momentary environmental conditions favour gully formation. From the hazard point of view they are much more important than those in the mountains. They represent a serious risk on cultivated area, especially on arable land. It is well known that the most fertile soils of Hungary were formed on loess and are cultivated intensively.

In summary all those areas, especially extended arable fields under large-scale cultivation, where the energy of water is not broken by anything are endangered.

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4. Wind erosion

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4.1 Introduction

Areas of windblown sand occupy about 20% of the country's territory. The thickness of sand varies from a few centimetres to 25-30 metres. Soil erosion by wind affects 16% of Hungary's surface. Damage is primarily caused on sandy soils (e.g. on the Danube-Tisza Interfluve, see Mezősi and Szatmári 1996), where crop yields may be reduced by up to 50%. Improperly cultivated peat soils with decomposed, powdery surfaces also have low resistance to wind erosion.

The main controlling factors of wind erosion are geomorphology, climate, soil properties, vegetation and land use. There is a strong seasonality in deflation with peaks in early spring and in summer. Seasonal changes of wind erosion are the consequences of precipitation availability and the extent and quality of vegetation cover in the period in question. Improper farming practices may lead to a powdering of the soil surface or compaction, and ultimately to deflation.

In Hungary the major factor of wind erosion is the low cohesion of a dry soil surface. The obvious preventive measure is to ensure a proper vegetation cover, which reduces turbulent air motion on the surface. Rye sowing, mulching or green manuring are the most often applied. Inorganic materials are also suitable for sealing the soil surface (e.g. clay, bentonite injection, resins or plastic foils (see Szabó 1977).

The consequences of wind erosion lead to serious problems for agriculture, the stirred-up dust influences air quality and is harmful for human health. From the aspect of environmental protection aeolian accumulation is also a harmful process leading to serious problems. The dust cover on the motorways endangers traffic safety. Aeolian accumulation can be described by the term inflation as the opposite process of deflation. The worst version of inflation caused by high velocity winds is called sand-blasting. Areas prone to deflation are prone to inflation as well.

Wind erosion risk will increase with global change, first of all due to the growing frequency of drought periods. The climate of Hungary will be warmer and drier in the future. In 50 years the average annual temperature will increase by 1.0–1.9 C° and precipitation will decrease (Bartholy et al. 2011). A reduction of soil moisture in winter and spring is expected. Climate change and more intensive human activities led to the expansion of wind affected land (Mezősi et al. 2016).

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4.2 Protection against wind erosion

In order to allow mechanization after the collectivization of Hungarian agriculture, large arable fields were formed in the 1960s and 70s. At the present time, where wind velocity is high and droughts are frequent, small (maximum 25 ha) plots separated by shelterbelts are recommended. Shelterbelts of rapidly growing trees (e.g. poplars and acacia) are preferred. Shelterbelts were introduced in Hungary following Soviet examples. They are now considered necessary on soils with poor water retention and which are liable to drought. The protecting effect of vegetation on wind velocity was measured with wind cups installed at each side of the shelterbelts. The measured data were successfully applied for the standardization of shelterbelts (Lóki, Négyesi 2006, Négyesi 2009).

As it is well known vegetation cover reduces wind velocity at the soil surface and so decreases soil erodibility. Threshold velocity increases with vegetation cover and the rate of wind erosion decreases with vegetation cover increase. Wind tunnel experiments prove that the wind transports less surface material from the surfaces under vegetation cover and thus the protective effect of a 10 cm tall vegetation against deflation could be well demonstrated. Plant rows sown parallel with the wind direction provide less protection for the surface than those sown perpendicular to wind direction (Lóki, Négyesi 2003). According to Bartus et al. (2017) windbreaks can decrease the erosive capacity of the wind in the case of winds with 15 m/s velocity. The most efficient protecting effect was detected if the plants are planted perpendicular to prevailing winds.

The application of chemical bonding agents creates a non erodible crust on the soil surface providing proper control against wind erosion. The method is expensive and maleficent for the environment, the use of sand-fixing chemicals has been limited to small areas (Lóki 1994). Irrigation may be an effective protection against wind-erosion. Irrigation with an amount equal to a 5 mm rainfall reduces the erosive effect of even a strong (15.5 m/s) wind 4-6 hours long depending on the soil texture. In shifting sand areas wind-erosion may start quickly under stronger (10-11 m/s) winds, even if and intensive, high volume and frequent irrigation is applied, as after a quick infiltration the top layer will be rapidly dry, even if the below lying layers still remain wet (Lóki, Négyesi 2003, Négyesi 2008).

Improper farming practices may lead to a powdering of the soil surface or compaction, and ultimately to deflation. Wind erosion control will be an issue of growing importance in the near future. It will be necessary to identify those areas where plant production is sustainable because of acceptable soil moisture conditions with sufficient protection against wind erosion.

4.3 Assessment of wind erosion

Wind erosion hazard has been subject to changes during the Holocene and also today. Changes are also due to the seasonality of wind erosion as mentioned above. In addition to natural controlling factors the influences of human society have to be taken into account as well. The most important anthropogenic factors are deforestation and improper cultivation of the soil surface. The role of irrigation is extremely significant. In the case of the lack of water in the upper soil layer, i.e. unfavourable soil moisture conditions not only the sand, or sand containing deposits will be moved, but the soil itself will be blown away by wind erosion as it happened in the United States in the 1930th. Because of the various anthropogenic activities

Fig. 1. Areas of actual and potential wind erosion hazard in NE-Hungary.
1 = areas of actual wind erosion hazard, 2 = areas of potential wind erosion hazard.

the areas potentially endangered by wind erosion can become areas of actual wind erosion endangerment.

An assessment of actual and potential wind erosion endangerment was carried out by Kertész (1976, see Figures 1-4). The areas endangered by wind erosion were taken from the map compiled by Stefanovits (1964). The map of the areas endangered by wind erosion was intersected with that of the wind-blown sand areas. Those areas which are not endangered by wind erosion but covered by wind-blown sand were identified as areas potentially endangered by wind erosion.

Kertész (1976) carried out an analysis based on the data of Állami Biztosító (State Insurance Company). The percentage of the areas damaged by wind erosion related to the whole insured area in a county was calculated as the average of the years 1968-1973 for each county of Hungary. The main result of this investigation pointed to the importance of sand areas other than wind-blown sand. The highest values were calculated for the counties of Komárom (1.21%) Pest (1.08%), Szabolcs-Szatmár (1.08%) and Heves (1.04%). Szabó et al. (1994) performed a similar evaluation on the expenses payed by insurance companies for wind erosion damages.

A method was proposed by Karácsony (1991) for the assessment of wind erosion. According to this estimation wind erosion endangers 30-40% of arable land (more than 1.5 million hectares). Wind erosion has been increasing during the last 2-3 decades and has degraded not only the traditionally sensitive sandy soils and peats, but most fertile soils as well (Stefanovits, Várallyay 1992).

Szabó et al. (2007) created a map of wind erosion hazard with four classes of

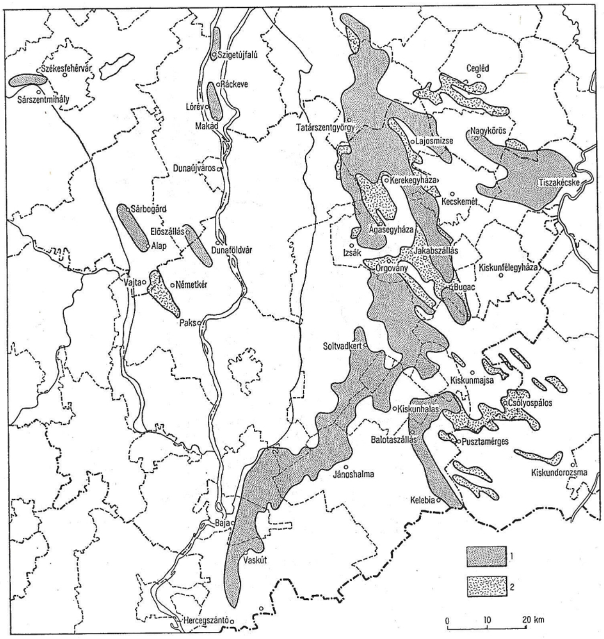

Fig. 2. Areas of actual and potential wind erosion hazard in Central Hungary.
1 = areas of actual wind erosion endangerment, 2 = areas of potential wind erosion endangerment.

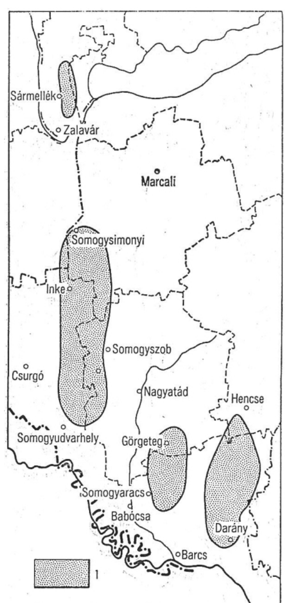

Fig. 3. Areas of actual wind erosion hazard in Southern Transdanubia, Hungary.
1 = areas of actual wind erosion hazard.

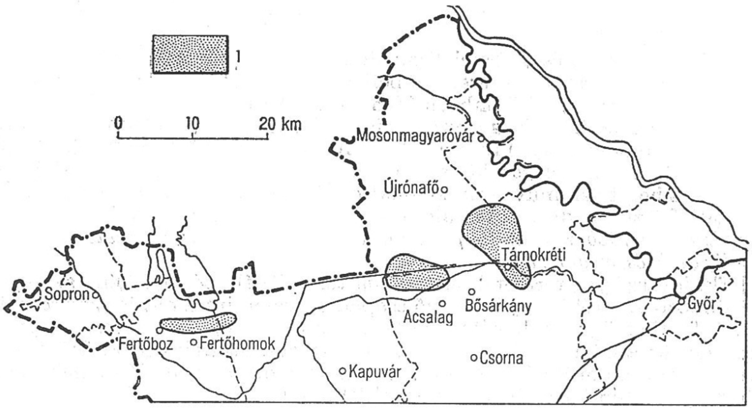

Fig. 4. Areas of actual wind erosion hazard in the Little Hungarian Plain.
1 = areas of actual wind erosion hazard.

wind erosion hazard in Hungary and they concluded that about 18% of the country are classified as more endangered by wind erosion.

A fuzzy logic method was applied by Mezősi et al. (2015) based on climate, vegetation, soil texture and land use data. The results were verified in the field on three test sites. Erosive winds were those exceeding velocity values >9 ms^{-1}.

4.4 Mapping of wind erosion

The two wind erosion maps (Figures 5 and 6) prepared by Négyesi and Lóki show potential wind erosion susceptibility.

For the identification of wind erosion classes the threshold values of wind velocity were identified by wind tunnel experiments and by determining the erodibility of 80 soil samples from a sample area of 5000 km^2. Soils with different texture types were categorized into erosion risk classes. The potential wind erosion map was compiled on the basis of the experiment results and of the CORINE land cover database.

Wind erosion is different according to various climatic, geomorphic, soil and land use conditions. Figure 5 shows potential wind erosion of Hungary. The surface of Hungary is classified into 5 classes including "no erosion", as shown in Figure 5 (Lóki 2004).

The potential wind erosion map was generated from the soil texture map prepared by the Institute for Soil Science and Geochemistry, Hungarian Academy of Sciences. Erodibility classes were related to soil texture categories of that map. The erodibility categories were identified on the basis of soil loss measured by wind tunnel experiments. Threshold wind velocity values corresponding to the categories were also taken into account.

Table 1. The main properties of erodibility categories (Lóki 2004)

Erodibility categories	Critical threshold velocity (m/s)	Amount of eroded material (gramm/5 minutes)	Soil textures types
slight erosion	>10.5	< 500	clay loam, clay loam, clay
moderate erosion	8.0-10.0	500-1500	loam, silt loam
high erosion	6.8-8.0	1500-3000	sandy loam
very high erosion	<6.5	>3000	sand, loamy sand

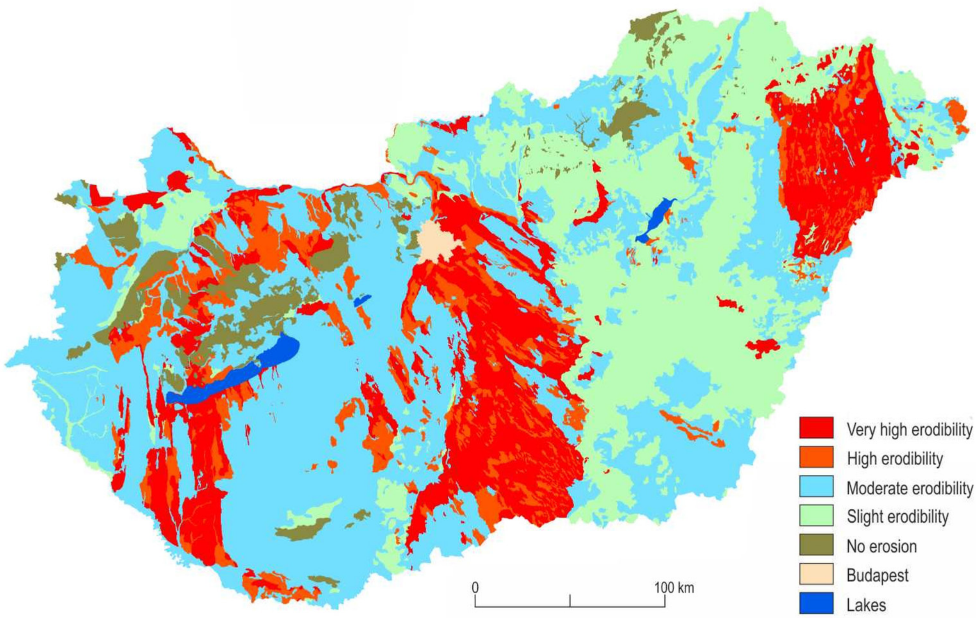

Fig. 5. Map of potential wind erosion of Hungary

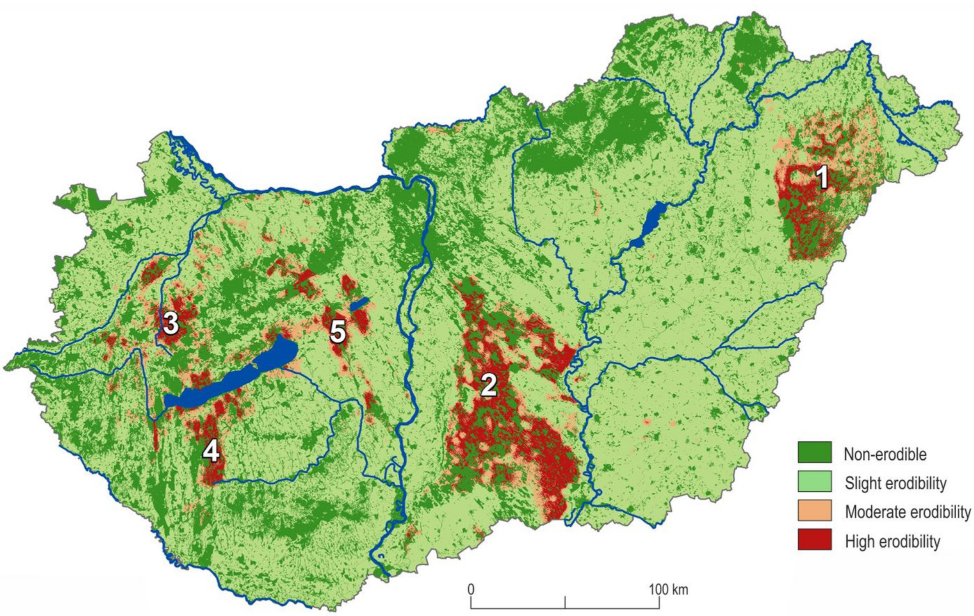

Fig. 6. Categorized wind erosion susceptibility map of the Hungarian soils. The five distinct areas with typically higher wind erosion risk are numbered: Nyírség (1), Danube-Tisza Interfluve (2), glacis in the foreground of the Transdanubian Mountains (3), Inner-Somogy (4), Transdanubian loess region (5).

According to this map, 26.5% of the country area are strongly or moderately affected by wind erosion. The critical velocity threshold value of erosive winds is 8.5 m s^{-1}. This map was compiled on basis of a simplified soil texture classification and critical threshold velocity. The latter was determined on the basis of wind tunnel measurements and the erodibiliy categories were added to soil texture types (Table 1).

The soil texture map of the uppermost (0-5 cm) soil layer was used for the evaluation of wind velocity threshold values. The map also identifies those areas which cannot be exposed to wind erosion because of their land use type.

Roughly 10% of the country is affected by high wind erosion risk. The reason for that are the vegetation cover and the incidence of erosive winds, i.e. wind with velocity exceeding the local critical threshold value. In most cases the critical velocity will not be exceeded during the year. Arable lands on lowlands with sandy soils are the most prone to wind erosion, because of the relatively small critical threshold velocity (6-7 m/s).

The percentage of wind erodibility classes shown on the map is as follows: (1) non erodible (31.2%), (2) slight erodibility (58.5%), moderate erodibility (5.6%), high erodibility (4.7%). The map presents the actual state of wind erosion. As mentioned above, the controlling factors of wind erosion vary in space and time, there are seasonal changes due mainly to changing soil moisture conditions and the role of cultivation/management technology, especially improper management is very important.

4.5 Conclusions

As a consequence of global climate change, the climate of Hungary is changing into a warmer and drier climate. Bartholy et al. (2011) estimate an average annual temperature increase of 1.0–1.9 C° and a precipitation decrease accompanied by a reduction of soil moisture in the winter and in springtime for the coming 50 years. The expected changes enhance wind erosion risk. Wind erosion control will be an important task in the future. Wind erosion control in the future must concentrate on prevention and on land management and engineering control practices as well as on the establishment of appropriate land use patterns.

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5. Water and wind erosion in the natural micro-region of Hajdúhát

Gergely JAKAB[1], József LÓKI[2]

5.1 Erodibility

The detailed map of the natural micro-region of Hajdúhát will be presented here as an example of how to compile maps in more detail.

The surface of the alluvial fan plain of Hajdúhát is covered by loess and silt at an altitude of 93-162 m. The southern part is moderately dissected by erosional valleys of Pleistocene-Holocene origin. The depth of the loess cover is 1-2.5 m. The highest thickness values are in the southern part reaching a depth of 10-15 m.

The erodibility of soils changes from N to S. The soils most resistant to erosion can be found in the northern part attached to the Tisza valley and to the dead channels. The soils of the lower lying parts are protected by a higher clay content and by the high organic matter content which is characteristic for the whole micro-region. The areas less resistant to sheet erosion are E and SE of Hajdúnánás and to NW of Debrecen.

Concerning present erodibility the micro-regions of Hajdúhát and Western Nyírség are different from the neighbouring micro-regions because a considerable part of their area is eroded. It should be mentioned, however, that the degree of erosion is generally low, only in some spots of the southern part dispose of medium erodibility (see Figure 1). Despite of that the thickness of the fertile layer exceeds 1 m.

Gully erosion is negligible despite of the presence of various loess and loess like sediments. There are practically no permanent gullies in the micro-region.

5.2 Wind erosion

The micro-region is a very low loess ridge. The properties of the loess cover are significantly different from those of other loess areas of the Great Hungarian Plain. Concerning grain size distribution silt and clay fraction occur at some places and wind-blown sand fraction at other spots and their proportion is substantially bigger than in the case of typical loess. The percentage of the loess fraction is much smaller (up to 40%). Another difference is the mixed occurrence of horizontal and vertical alternation of layers of fluvial and eolian origin (Lóki et al. 2014).

In the northern part of Hajdúhát where it adjoins Nyírség and where the elevation a.s.l. exceeds 10-100 m only at some places an important sand movement took place in the first part of the Late Pleniglacial period and various sand forms developed like in the adjoining micro-region of Nyírség. It is a typical characteristic of the region that surface forms consisting exclusively from wind-blown sand do not occur anywhere.

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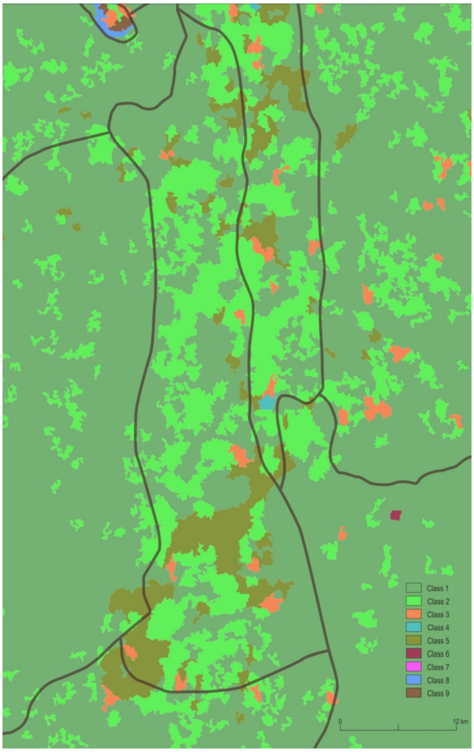

Fig. 1. Erodibility classes of Hajdúhát (after Pásztor et al. 2015). The legend categories (Class 1-9) correspond to the following t ha^{-1} values: 1= 0-0.5, 2 = 0.5-1, 3 = 1-1.5, 4 = 1.5-2.0, 5 = 2-5, 6 = 5-8, 7 = 8-11, 8 = 11-100, 9 = > 100

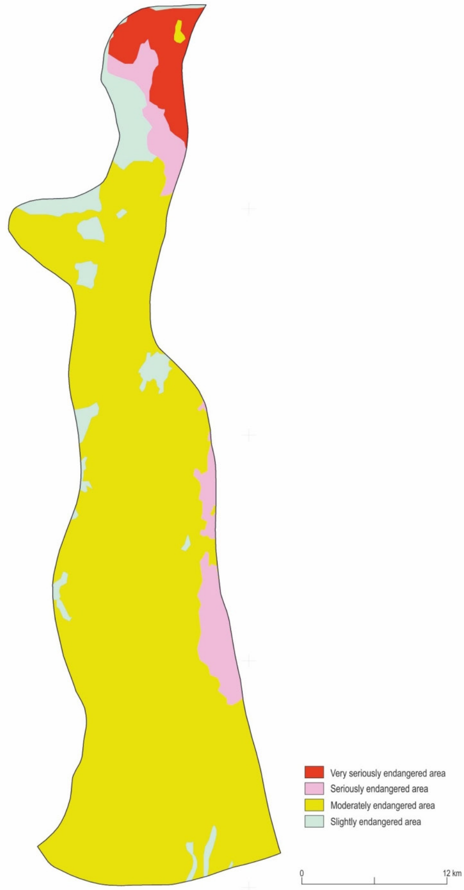

Fig. 2. Map of potential wind erosion of Hajdúhát

The sand dunes are covered by sandy-loess, loess-sand, and loess with a depth of up to 4 m at some places. At the border region to Nyírség areas consisting of loess and loess like sediments, covered by wind-blown sand loess and loess like sediments and surfaces consisting of wind-blown sand and covered by loess strata may equally occur.

As a consequence of the grain size distribution of surface and subsurface strata most of the micro-region belongs the areas of medium risk from the aspect of wind erosion. Wind erosion risk is higher in the northern and eastern border regions where wind-blown sand and loess sand cover the surface. This can be seen on the map presented in Figure 2. Wind erosion occurs first of all in April, at the beginning of the vegetation period after ploughing when the surface is not yet covered and protected by vegetation.

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6. Salinization, secondary salinization

Balázs MADARÁSZ[1]

6.1 Introduction

Salinization is a natural process of soil formation. Saline soils represent a special, unique value and they have to be protected. Saline areas belong to those of nature protection. The extension of saline areas is one of the biggest in Europe, i.e. 560000 ha occupying 6% of the country area (Tóth et al. 2008.) They develop in those natural micro-regions of the Great Hungarian Plain where shallow salty ground water is available. Their development is related to water-soluble salts, mainly to sodium salts. The characteristics of saline soils is determined by the quantity and quality of salts. Physical, chemical and biological soil properties degrade with growing salinity leading to the decrease of their fertility.

Secondary salinization is the consequence of anthropogenic activities. The areas of secondary salinization imply serious soil degradation problems as. The global estimate of the area becoming unusable because of secondary salinization is 1 million ha in a year. Previously good quality soils become saline because of rising groundwater levels as a result of improper irrigation and inappropriately planned irrigation systems. The estimated area of secondary salinization in Hungary is 400 000 ha (KSH 1986). Future climate change may reduce groundwater levels slowing down the process of secondary salinization, however, increasing evaporation calls for the necessity of irrigation on more and more agricultural areas leading to rising groundwater levels and the consequences is secondary salinization.

6.2 Present state of saline areas in Hungary

Research, survey and mapping of saline areas has been in the focus of science and practice for a long time. At the beginning the main objective was how to utilize them. Recently the protection of natural values and a better cognition of the development processes of saline soils is in the focus of research activities. The most detailed survey of saline soils and recording information on them in a well ordered digital database was carried out in the framework of agro-topographic mapping (RISSAC 1991).

Saline soils and soils saline in deeper layers are presented in Figure 1. Map analysis was carried out in an ArcGIS 10.3 environment. The databases contain the following soil types: Solonchak, Solonchak-Solonetz, Meadow Solonetz, Meadow Solonetz turning into steppe formation.

Meadow Solonetz soils have the largest territorial extension (2750 km^2), half of all saline areas. In addition to the above-mentioned soil types there are other soils belonging to another soil type at

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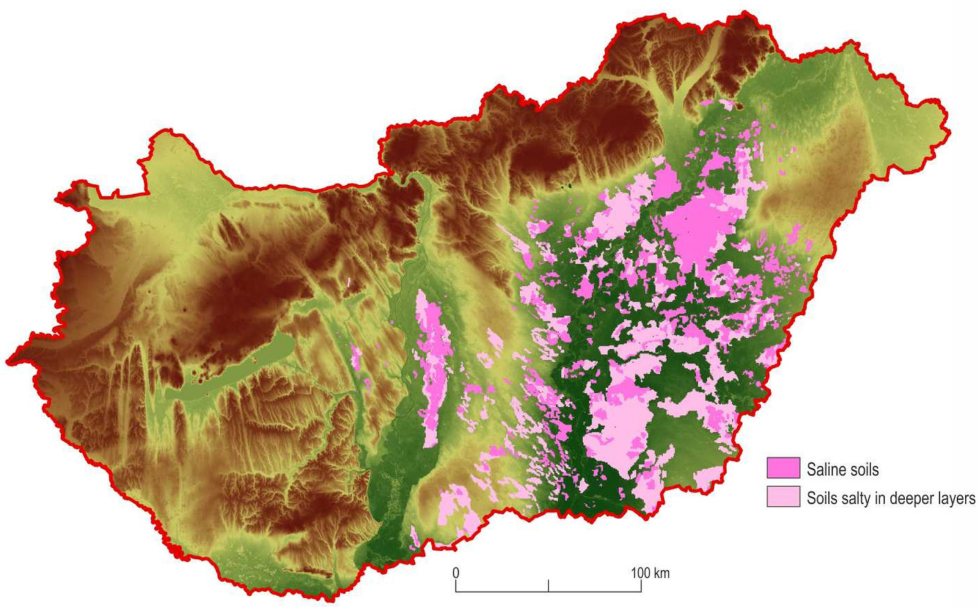

Fig. 1. Saline soils of Hungary (RISSAC 1991)

the moment, they may become saline due to the effects of environmental and anthropogenic factors. Most of them are salty in deeper layers: calci-myceliers lowland chernozem salty in deeper layers, meadow chernozems salty in deeper layers, solonetz meadow chernozems salty in deeper layers, solonetz meadow soils. The total area of these soil types is 6615 km^2, 7.1% of the country area. Meadow chernozems salty in deeper layers have the greatest territorial extension (3321 km^2).

Saline areas can be found in 67 natural micro-regions of the country. The number of natural micro-regions with saline soils >1 km^2 is 58. The largest saline areas are in the following micro-regions: Hortobágy (939 km^2), Tiszafüred–Kunhegyes plain (359 km^2), Csongrád plain (296 km^2), Szolnok–Túr plain (277 km^2), Bihar plain (273 km^2), a Dévaványa plain (268 km^2).

Concerning the percentage of saline soils within a natural micro-region the Hortobágy takes the first place with 60%, without the soils salty in deeper layers. Dévaványa plain is on the second place with 48%. In the case of the micro-regions of Bihar plain (38%), Tiszafüred-Kunhegyes plain (37%) and Nagy-Sárrét (36%) the proportion is more than one third. The share of saline area is over 10% in 24 micro-regions. Taking the soils salty in deeper layers into account, Hortobágy is on the first place with 77%. It is remarkable that the percentage is 73% on the Csongrád plain where the saline areas occupy only 17%.

The proportion of saline soils and salty in the deep layers is more than 50% in six micro-regions: Dévaványa plain, Nagy-Sárrét, Tiszafüred-Kunhegyes plain, Körösmenti plain, Borsodi-Mezőség, Békés plain.

6.3 Maps of sensibility and hazard

Secondary salinization is related to human influence. As mentioned above, improper irrigation and incorrect planning of irrigation systems lead to groundwater level rise and because of the increased

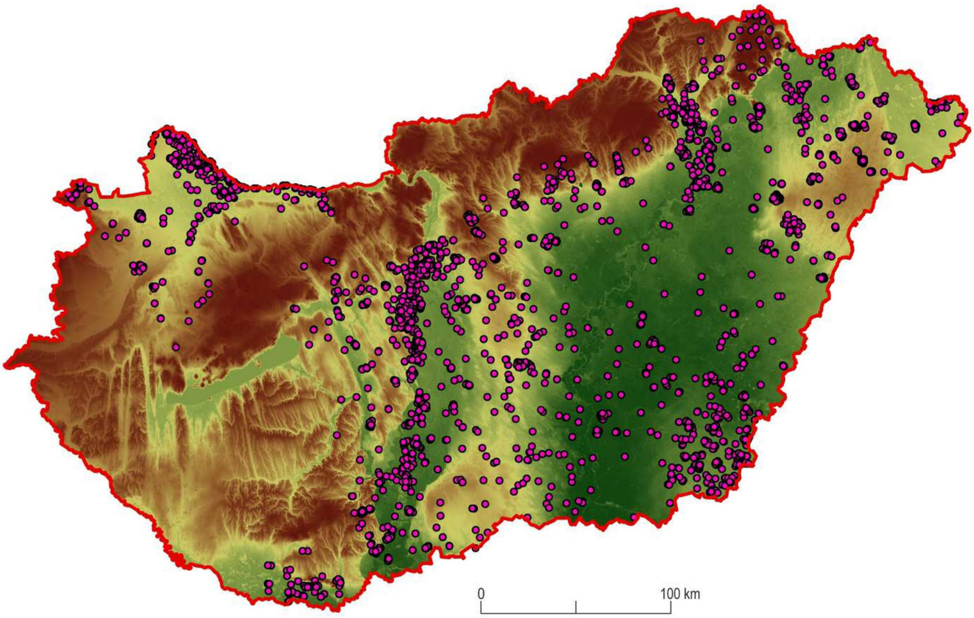

Fig. 2. Distribution of the 3494 lowland groundwater wells used for the groundwater quality data

evaporation the accumulation of water soluble salts, mainly Sodium starts.

An attempt was made to identify and categorize the areas potentially sensitive to secondary salinization. For future planning it is of crucial interest to reveal the sensitive areas on the level of micro-regions. The critical groundwater level equation of Kovda (1973) was applied which is based on the depth to and the salt content of groundwater:

$$d = 0.0659s^2 + 0.8798s + 0.2406$$

where d = is groundwater table depth and s = salt content of groundwater in g/l.

Groundwater depth changes in time. Measured, registered and processed groundwater data (1981-2010) of the hydrographic master stations of the water authorities in the area were used in the investigation. Concerning the temporal resolution of the data, daily registered data, in the case of measured data daily averages were used. The data employed for the preparation of the groundwater level map originate from VIZIR (Water Management Information System) and within this MAHAB (Hungarian Hydrological Database) and in the case of raw data VA (Water Data Warehouse). For map compilation an iteration process was applied, i.e. the revision of the prepared material, corrections and after the repetition of these steps a new revision followed.

The process of data preparation included filtering of outliers and the identification of the periods with incomplete data series. Salient data may distort yearly averages and if the errors accumulate the average value of the period may change. In the case of a data series of 30 years this could be neglected, however, in some cases distortions may appear when during data classification. The revision process included the control of yearly data and of outliers. Outliers were modified or deleted, on the basis of hydro-meteorological and other background factors of the given year and area. The

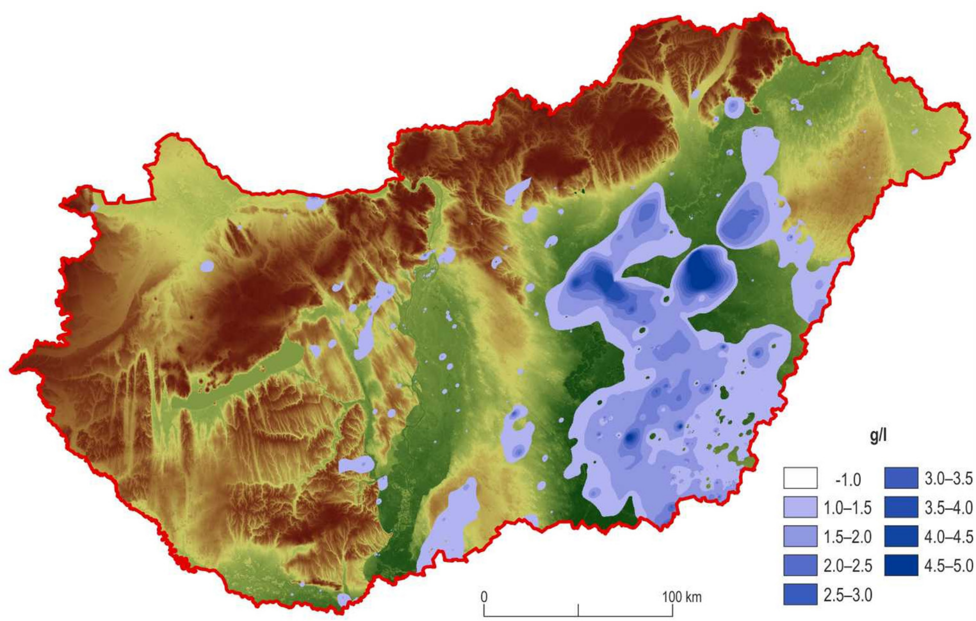

Fig. 3. Average dissolved salt content of lowlands (2000-2012)

map showing the distribution of the mean depth of the groundwater level between 1981-2010 was performed by kriging, i.e. by a linear assessment method, applying the ArcGIS 10.3 software. The original vector dataset was converted into a raster dataset with 250 × 250 m resolution. In addition to the 1981-2010 groundwater depth data, water quality data of 3502 dwells of the GDWM (General Directorate of Water Management) were included in the analysis. The 2000-2012 values of average specific electrical conductivity were retrieved from groundwater dwell and spring data. After the corrections the data were ordered and filtered. The data of altogether 3494 dwells were put into the ArcGIS database (Figure 2).

The application of the Kovda equation requires the TDS (Total Dissolved Solids) transformation of EC data. The transformation was performed by the following equation:

$$TDS = EC \times 0.641$$

The territorial extension of the dwell data was carried out by the Inverse Distance Weighted (IDW) interpolation method. IDW is a simple interpolation method where the interpolated surface depends from the mutual distance of the stored points. The method is based on the first law of Tobler which states that "everything is related to everything but near things are more related than distant things". The method is accurate but it is not applicable for modelling higher values than the input values. The results are presented again in a 250 × 250 m raster. The average dissolved salt content values are presented in Figure 3.

The map of "critical water depth" (Figure 4) was created by the help of the raster databases of groundwater and groundwater salt content by the application of the Kovda function.

The areas sensitive (susceptible) to secondary salinization were identified from the GDWM water depth data, critical water depth and the saline areas of the

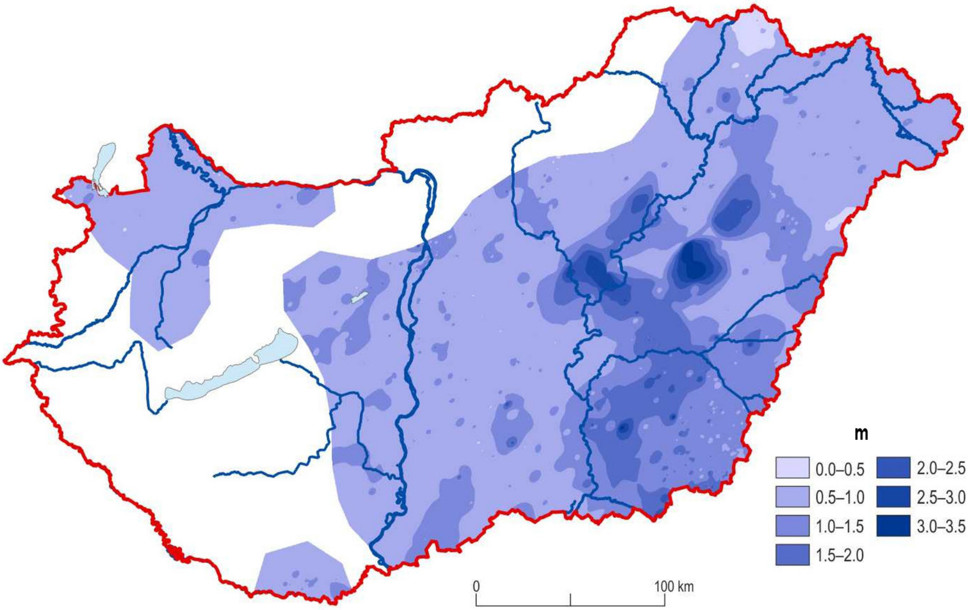

Fig. 4. Critical water depth level of lowlands from the aspect of salinization as a function of salt content of the soil

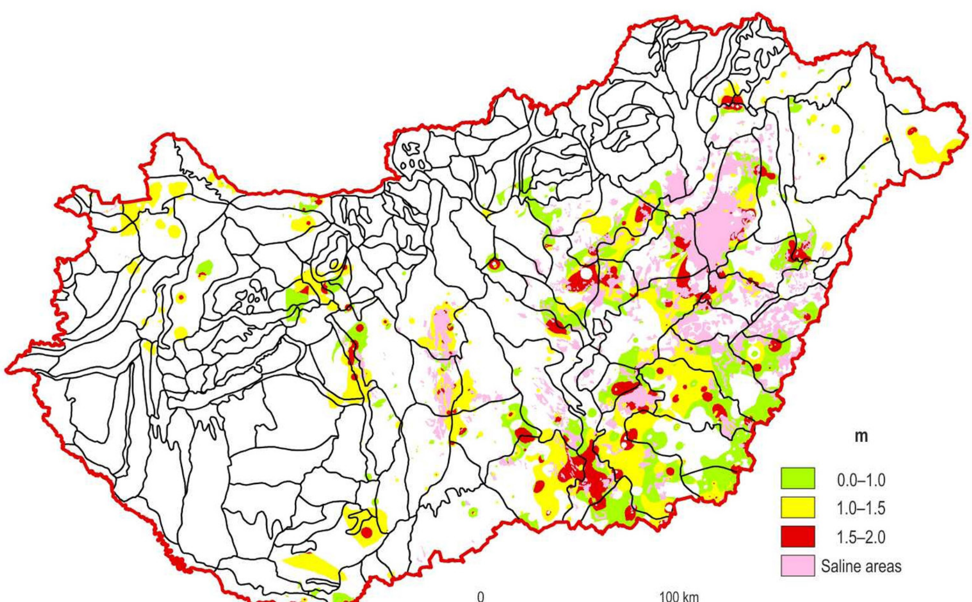

Fig. 5. Extent of areas susceptible to secondary salinization as a function of potential rise of water level

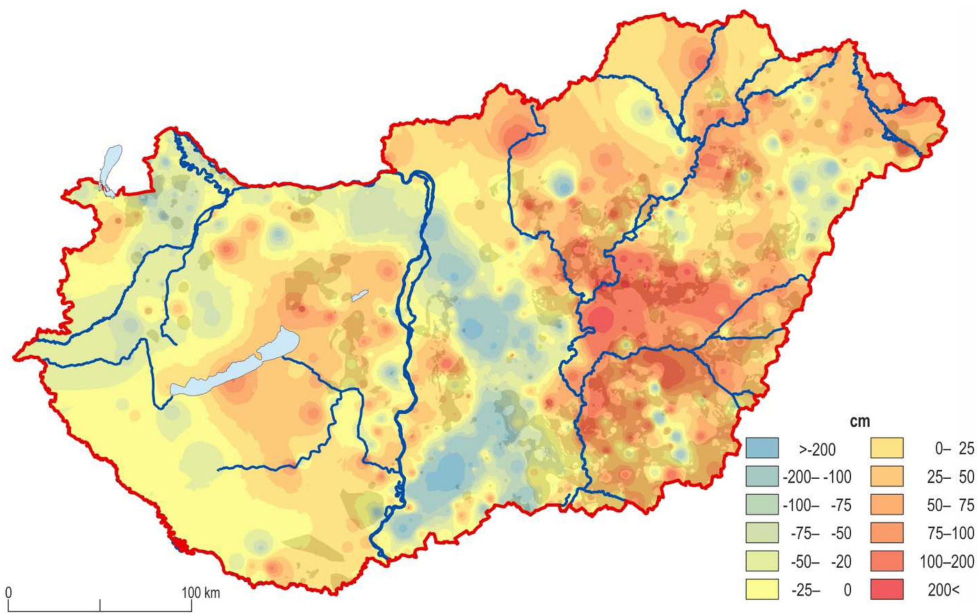

Fig. 6. Average groundwater level differences between the values of 2000 and the average of 1956-1960 (compiled by the author, based on VITUKI Environmental Protection and Water Management Research Institute data and on Szalai 2003). Blue = groundwater level subsidence, red = groundwater level rise, grey = areas susceptible to salinization in case of groundwater level rise

agro-topographical map (Figure 5). On the basis of the results it can be asserted that one meter rise of groundwater depth would only affect a smaller area (34 000 ha), but in the case of a 1.5 m rise the size of the areas affected by secondary salinization would be greater than 145 000 ha and a rise of 2 metres it would be 235 700 ha.

Those areas are the most susceptible and most endangered where the process of salinization can start due to a small water level rise of less than one meter. These territories are attached to existing saline areas along the Tisza, Maros and Körös rivers. The most extensive endangered areas are the following micro-regions: Csanád ridge, Marosszög, Csongrád plain, Békés plain, Körösmenti plain and Gerje-Perje plain. There are several micro-regions along the above-mentioned rivers susceptible to changes between one and two metres, e.g. the Sand ridge of Dorozsma-Majsa, Csongrád plain, Békés plain etc. Further micro-regions susceptible to changes between one and two metres are also at the upper part of the Tisza river (Szatmár plain) and along the Danube: The plains of Csepel, Solt, Tolnai-Sárköz, Káloz-Igar loess ridges etc.) It should be noted that the degree of future groundwater level changes will be different in various parts of the country. They will be present in these micro-regions as a result of improper irrigation, faulty designed channels etc. The susceptibility map directs our attention to those areas where careful decision making and planning is required preceding new investments and the application of new technologies if they may affect the groundwater level to avoid the degradation of a very important natural resource of Hungary, i.e. of our good quality soils.

6.4 Climate change

It is difficult to forecast how the groundwater level in the critical micro-regions will change. This will be shown on the example of the 2010s. Drastic groundwater level subsidence happened at the beginning of the 2010s as a result of successive dry years. A rainy period followed the dry years triggering the increase of the groundwater level and the process of salinization took over again.

In 2000 a map was prepared by Institute of Hydrology of VITUKI Environmental Protection and Water Management Research Institute. The comparison of the average groundwater level values of 2000 with those of 1956-1960 is shown in Figure 6. Concerning groundwater table changes reverse processes can be observed in the Great Hungarian Plain. A remarkable groundwater level subsidence can be seen on the Danube-Tisza Interfluve whereas the rise of the groundwater level is the case in Tiszántúl (Trans-Tisza region) and in the area of the Körös rivers. Considering that from present water level data most areas susceptible to salinization are on the Tiszántúl and assuming the continuation of the trend shown on the map of VITUKI, serious salinization problems can be expected in the not yet saline areas of the Tiszántúl region.

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7. Physical degradation

Balázs MADARÁSZ[1]

7.1 Introduction

As discussed in the introduction of this book (Chapter 1), at the beginning the issue of landscape degradation arose from the aspect of the soil, i.e. from the aspect of a single landscape factor. The degradation of the soil is an important practical issue having been investigated mainly by soil scientists for a long time.

As it has already been mentioned, soil degradation means landscape degradation at the same time, because the change in one landscape factor affects all the others and, thus, the landscape itself as a special unit (Kertész 2008). Human induced soil degradation processes are not necessarily the consequences of soil cultivation. Soil degradation can be prevented, its rate can significantly be reduced by applying various soil and environment friendly conservation techniques (Várallyay 2003). Physical soil degradation processes include compaction, structure destruction, surface pulverization, silting up of the surface and surface sealing, caused mainly by human activities such as overtillage, application of heavy machinery etc. like in most places of intensive agriculture in the world.

A classification system of Várallyay and Leszták (1990) was elaborated for Hungarian soils with regard to their susceptibility to physical degradation:

1. Non-susceptible soils: sandy soils without structure and with a low content of cementing compounds (such as carbonates or sesquioxides);
2. Slightly susceptible soils: medium-textured soils with well-developed structure and high aggregate stability;
3. Moderately susceptible soils: medium-textured soils with moderately developed structure and low aggregate stability;
4. Soils susceptible to compaction and surface crusting but not to structural damage: sandy soils without structure but with a high content of cementing compounds, mainly carbonates;
5. Soils susceptible to structural damage and compaction: heavy-textured soils of swelling-shrinkage character and low structural stability;
6. Soils susceptible to both structural damage and compaction due to salinity-alkalinity;
7. Organic soils (peats);
8. Shallow soils (solid rock or cemented layer near the surface).

Soil structure is influenced by various factors: elementary particle size, grain size distribution, quality and quantity of binding material of aggregates (organic and mineral colloids, humus, clay minerals, iron and aluminium oxides, calcium carbonate). Natural factors (freezing – melting, shrinking–swelling, mechanical effect of roots, raindrops etc.) and anthropogenic factors (cultivation,

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treading) may modify the already developed soil structure. Structural elements can be evaluated from various aspects like from the aspect of morphology (form and state of development) and from the aspect of agronomy (size).

7.2 Physical soil degradation in Hungary

The degradation of soil structure, the collapse of aggregates is caused by mechanical effects, e.g. by the effect of soil cultivation under too dry conditions and/ or by the effect of splash. Due to the effects of rainfall and irrigation the disintegrated, pulverized soil will be soaking wet, silted up during sedimentation and a soil crust develops after drying (Kátai 2011). Pulverization supports wind erosion risk, too. Structure degradation will be further enhanced by compaction and treading (walking on wet soil, cultivation at the same depth several times). Soil compaction to some extent is estimated to be present on nearly 50% of Hungarian cropland (Birkás et al. 2000). Soil crusting may be also the result of natural processes like too high rainfall amounts and waterlogging. The extent of compaction changes according to pressure, deformation repetitions and moisture content. In some cases the compaction may extend on the soil surface and in the deeper layers equally (Birkás et al. 2004.). As a consequence of soil structure degradation, i.e. of compaction the water storing capacity and infiltration capability of the soil decreases. runoff and erosion increase, porosity decreases, root development is hindered, yield decreases and production costs grow. In former times the general opinion about the necessity of favourable soil conditions was prevailing, i.e. for seeding and for the healthy plant development ideal conditions were inevitable. For these favourable conditions in many cases a dusty seedbed was formed. According to the analysis of a longer period this is harmful because of the risk of structural deterioration, pulverization and deflation (Farsang 2011).

More than half of Hungarian soils are subject to physical degradation to some extent. However, their exact extension is not known. According to previous surveys 13% of Hungarian soils are strongly, 18% moderately and 23% slightly susceptible to physical degradation (Farsang 2011).

7.3 Susceptibility to physical soil degradation

A more detailed survey on physical soil degradation, concerning the area used for agriculture would be needed in the future. This objective of this study was to answer the question which parts of the country are susceptible to physical degradation, considering soil properties and land cover using available databases.

Susceptibility categories do not correspond directly to the degradation degrees, it is highly probable, however, that the areas used for arable cultivation and strongly susceptible to physical degradation are affected by the processes of physical degradation to a certain extent. It should be noted that the rate of degradation can be reduced and preceded by applying a suitable soil conservation technology, as mentioned in the introduction. There is no country-wide database about the applied conservation technologies and therefore this factor couldn’t be taken into account.

The analysis was carried out in ArcGIS by using the agrotopographic maps of the Institute for Soil Science and Geochemistry, Hungarian Academy of Sciences (RISSAC 1991)and the CORINE Land Cover database (Büttner et al. 2002).

For the preparation of the susceptibility map (Figure 1) soils were reclassified according to texture classes (1 = clay, clayey loam, loam; 2 = sandy loam; 3 = sand, peat, coarse fragments), organic material stock

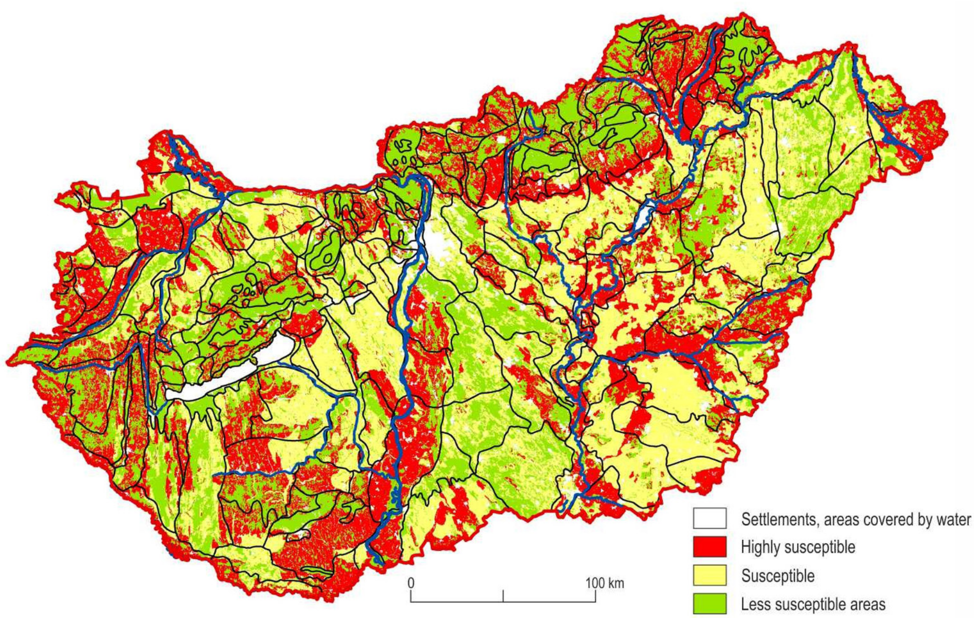

Fig. 1. Areas susceptible to physical degradation (white = settlements, areas covered by water; red = highly susceptible; yellow = susceptible; green = less susceptible areas)

(1 = < 100 t ha^{-1}; 2 = 100–300 t ha^{-1}; 3 = 300 t ha^{-1} <). Three CORINE categories were created allowing for weighting soil properties data (0 = artificial surfaces, e.g. settlements, areas covered with water; 1 = arable land; 2 = forested areas). The map of the areas susceptible to physical degradation was created by map overlay. Finally the data of the 250 × 250 m raster were assigned to the polygons of natural micro-regions.

The susceptibility categories are equally distributed (29-31-33%). Soils highly susceptible to physical degradation can be found on 29% of the country area (1). The less susceptible, or not susceptible areas have the greatest territorial extension of 33% (3). More than 50% of the area is highly susceptible to physical degradation in the case of forty-four natural micro-regions. The most endangered micro-regions are as follows: Harangod, Szerencsköz, Cserhátalja, Western Mátraalja, Kapuvár plain, Szerencs hills. More than 70% belongs to category 1 in these micro-regions. Southern Baranya hilly country has the highest value of 67.4%. This micro-region has the biggest absolute value of susceptible area among the micro-regions with an extent of nearly 900 km^2. The extent of highly susceptible areas is remarkable high in the following micro-regions: Szatmár plain (680 km^2, 57.6%), Körösmenti plain (668 km^2, 54.6%) and Kalocsai-Sárköz (664 km^2, 63.6%). Non-cultivated and forested areas as well as areas with favourable soil conditions are less, or non susceptible to physical degradation. The percentage of category 3 is more than 90% in the following micro-regions: Central Börzsöny, Bükk plateau, Gánt basin, Vértes plateau, Upper Mátra, Aggtelek mountains, Southern Bükk, Alsó-hegy.

A short statement on the influence of climate change on physical soil degradation follows. As already discussed, the main and most important triggering factor of physical degradation is cultivation. Compaction and/or pulverization is due to cultivation operations carried out at improper time and with heavy machinery. It is therefore evident that the effect of future climate change on physical soil degradation is not very important. However, if the extent of the areas covered with inland excess water will increase, it will influence the distribution and extent of the areas susceptible to physical degradation as well.

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8. Mass movements

Dénes LÓCZY[1], Edina JÓZSA[1], József SZABÓ[2]

8.1 Introduction

The geomorphological study of mass movements reveals landslide hazard and the role landslides play in land degradation. Research serves prevention and mitigation of damage caused by active movements, the prognostication of their reactivation, while the necessary engineering works are implemented by enterprises in geotechnics, soil mechanics and geodesy (Szabó 2008). The main tool of geomorphologists in mass movement investigations is the comparative analysis of landform parameters, complemented by palynological analyses, radiocarbon dating (e.g. Szabó 1997, Szabó, Félegyházi, 1997, Magyari et al. 2000), and most recently by the interpretation of remotely sensed images and GIS analyses (Vágó 2009; Gerzsenyi, Albert, 2018). It was found that in the transitional period between the Late Pleistocene and Preboreal, when the permafrost thawed, landslide activity increased remarkably.

The interrelationships between weather conditions (first of all precipitation regime) and mass movements (Juhász 1999; Juhász, Schweitzer 1989; Szabó 2003) revealed that extreme winter precipitation often generates major landslides. Although the downscaling of global climate change scenarios most probably prognosticates a climate closer to the Mediterranean type, involving increased aridification (Kertész, Mika 1999), higher winter rainfall probability will upkeep landslide hazard on agenda in Hungary (Szabó 2003).

8.2 Landslide hazard in Hungary

The distribution of landslides by the physical microregions of Hungary (Szabó, 1996, 2008) provides us with a general picture about the areas where mass movements can be expected to occur in the future.

A statistical analysis of available inventory data (Józsa et al. 2019) also revealed the regional distribution of mass movements in Hungary (Figure 1). They are mostly associated with hills and uplands of unconsolidated sediments, particularly in the following regions of the country (Szabó 1996, Juhász 2004):

- The maximum number of events (56) was recorded in foothill areas of Neogene clays and overlying loess: in North Hungary in the Eger Bükkalja and in West Hungary in the Vas Hegyhát.
- Significant number of mass movements occurred in foothill areas: in South West Hungary in the South Baranya Hills (111) and the Baranya Hegyhát (53), in North Hungary in the Eger Bükkalja (68) and in West Hungary in the Vas Hegyhát (56).

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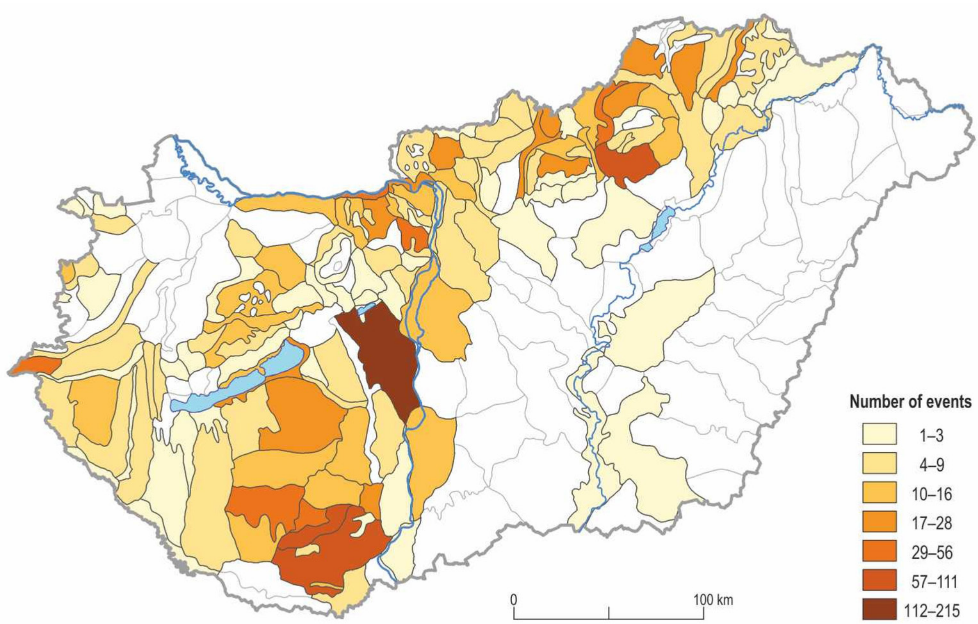

Fig. 1. Number of mass movements by physical microregions

- Movements are typical in loess-covered hilly regions (Tolna and Baranya Hills, including the Mecsek and Villány Mountains) where relative relief (valley density) is high (246).
- Similarly abundant are landslides in some basins of low mountains, such as the Ózd–Egercsehi (33) and the Nógrád Basins (20) in North Hungary and in the Veszprém–Nagyvázsony Basin (11) in Transdanubia.
- Similarly, abundant are landslides in some basins of low mountains, such as the Ózd–Egercsehi (34) and the Nógrád Basins (21) in North Hungary and in the Veszprém–Devecser Graben (13) in Transdanubia.
- In mountains of volcanic origin (including the Tapolca Basin, Tátika Group, Badacsony-Gulács, Balaton Highlands, Veszprém-Nagyvázsony Basin, Visegrád Mountains, Börzsöny, Central Cserhát, Mátra, Bükkalja, Hegyalja, Tokaj Hill, Szerencs Hills) usually inactive landslides have been detected (204).
- Among the valleys of major rivers, including the right bank of the Danube (four sections above Budapest and six sections below Budapest, 26 events); the left bank of the Hernád river in the northeast in three sections (27); the Zagyva (37); the Rába, the Tarna and the Sajó Valleys (9–9). Riverbank collapses along the Tisza River have not been inventoried.
- Among the valleys of major rivers, including the Danube (four sections above Budapest and six sections below – maximum number of recorded events in Central Mezőföld along the right bank [213]), the left bank of the Hernád river in northeast in three sections (22), the Zagyva (20), the Tarna (12), the Rába (9) and the Sajó Valleys (7). Riverbank collapses along the Tisza River have not been inventoried.

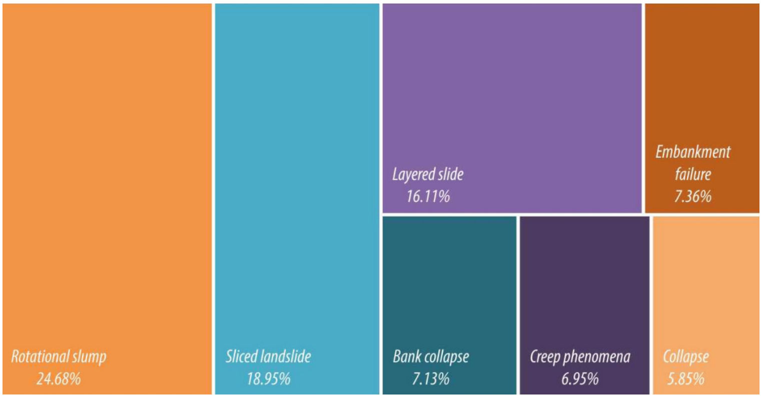

Fig. 2. Types of mass movements with more than 100 events

- Along the shores of the lakes Balaton and Fertő further unstable high bluffs occur (ca. 46 landslides).
- Human-induced movements are typical of spoil heaps in mining districts. (The national statistics are not complete for this type of movement.)

It is to be noted that within the individual microregions the distribution of landslides is rather uneven. For instance, in the Central Mezőföld it is only the eastern margin which is endangered by movements.

Apart from the spatial distribution of movements the inventory data also allows an overview of the major features of the surveyed events. Considering the types registered in the dataset it was found that rotational slumps, sliced landslides and layered slides are the most widely occurring phenomena (Figure 2).

The state at the time of the survey and information about the periodicity of the movements was also registered. From a temporal aspect around 44% of events are still ongoing (Figure 3A). Considering the state of the events, this high number is supported by the significant proportion of still moving landslides registered (Figure 3B).

The triggering factors listed in the survey data provide a valuable attribute besides the spatial location and type of the mass movements, revealing information that can help with the mitigation and prevention. However, during interpretation, one must

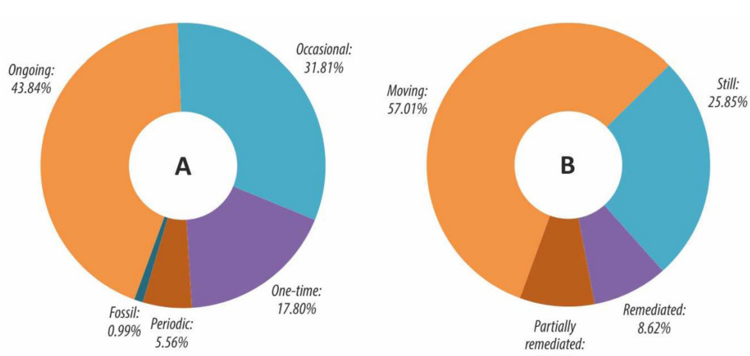

Fig. 3. Distribution of the periodicity (A) and state (B) attributes registered. No data entries excluded

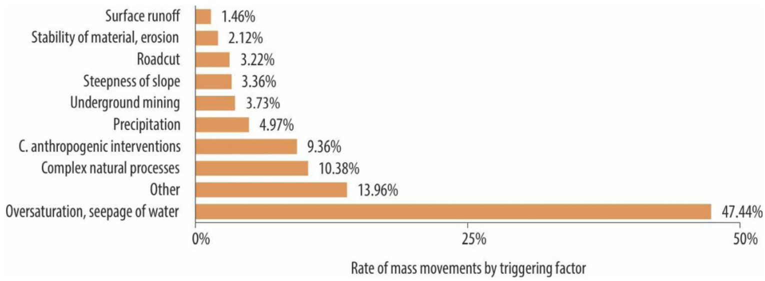

Fig. 4. Distribution of the triggering factors listed in the national survey. No data entries excluded

consider the uncertainties resulting from the different surveyors' preceptions 9 main categories could be separated, while in the category 'other' different events, such like earthquakes and pipe bursts were also mentioned (Figure 4).

In the sections below some case studies are briefly presented which illustrate the diversity of geological backgrounds and types of landslides in Hungary. The descriptions are based on partly 'classical', partly very recent investigations and papers. The temporal regimes of slides are seldom monitored (some high bluffs along the Danube and Tisza are exceptions) and repeated surveys are not common either.

8.3 Case studies

8.3.1 Landslides in loess-covered hills

In Hungary some of the 'classical' studies of landslides were concerned with the loess-mantled Tolna Hills and, within that, the particularly heavily dissected Szekszárd Hills in Southeast Transdanubia (Southwest Hungary).

The stratigraphic position of impermeable clay beds in the loess-paleosol sequences is a fundamental control of the generation of landslides since it governs the development of preformed slip planes which allow the mostly rotational movements of loess blocks (Ádám 1967). Under the loess-paleosol sequence, at most 60-metre deep, the surface of the anoxic blue-green clays (deposited in Lake Pannon up to the Pliocene) dipping at 10-15° towards the Kapos Valley function as an excellent slip plane. The dip of clay beds determines the type of landslide, its failure front and depth. In the Tolna Hills the high relative relief also contributes to slope instability. The majority of landslides dates back to the wet interglacial stages of the Pleistocene, when movements were common along the marginal escarpments, widened valleys and created broad loess ridges and narrow crests (Ádám 1969). Some landslides could be reactivated on numerous occasions during the Pleistocene, resulting in a complex assemblage of landforms (Ádám 1964). The fossil landslides are often buried under several metres of younger loess deposited in situ or redeposited by gelifluction (frost action). Even more marked but of smaller dimension are the tongues of Holocene landslides (e.g. along the eastern escarpment of the Szekszárd Hills – Ádám 1964). In historical times, human action (removal of support to slopes, oversaturation caused by changes in groundwater conditions) generated small-scale slumps along the perimeters of old slides, particularly along the right-bank margin of the Kapos Valley (Ádám 1969).

8.3.2 Landslides in foothill areas

Another minutely studied hilly area with abundant landslides is the Cserehát Hills (Szabó 1998). The main mass of the hills is composed of deposits of Lake

Pannon in different grain size categories (clays, sands and gravels), which are of expressedly low stability. The reason for this lies in the high proportions of blue-green or brownish-yellow clays (up to 70%) which are to a large part swelling clays. Incising valleys cut across aquicludes and aquifers repeatedly and provide favourable conditions for oversaturation. Pleistocene landslides affected both Upper Miocene and the overlying Pleistocene fluvial sediments. Most of the hillslopes are covered with these reworked slope deposits.

With the exception of patches in the Sajó Valley, the Cserehát Hills have no loess mantle. This can be explained by the high intensity of slope processes. When deposited on the surface, wind-borne dust was mingled with slope deposits. Therefore, no loess mantle could develop – even if high proportions of silt can be found in the grain size distribution of exposures (particularly in the southern Cserehát).

The longitudinal profiles of valleys show rather uneven curves in the Cserehát, which is also primarily explained by active landslides. The importance of mass movements essentially equals to that of sheet wash and gully erosion in the geomorphic evolution. The majority are layered slides (in Szabó's terminology – Szabó 1996) cutting through aquifers above the base point or mantle slides with slip plane beneath the soil or slope deposits (Szabó 1985). The accumulation of minor heaps takes place in repeated stages, while carpet-like slides occur as a single event. Typical rotational slumps are rare and have a large area (from hundreds of square kilometres to some hectares) relative to their depth.

In the southern foothills of the Bükk Mountains (Bükkalja) mass movements happen in two geological formations. Miocene marine sands and clays are locally covered by Pleistocene deposits. The high clay content of the series is an important factor of the generation of shallow landslides since pore pressure can increase in the clay beds within a short time and reduces shear strength.

In the same microregion Miocene volcanism produced rhyolitic and dacitic tuffs. Welded ignimbrites are of relatively high stability and in the dissected topography form cliff walls of 5-10 m height (Zelenka 1999), while in unconsolidated tuff layers wetting reduces stability to 40-60% (Kleb 1999) and generates translational movements. Because of the low relief and low clay contents, however, these movements are not decisive in the geomorphic evolution of the microregion.

In some densely populated and agricultural foothill areas landslides pose a significant threat to property. This is the case in the Gerecse Mountains, too, and, therefore, these processes have been studied for several decades there (Schweitzer 1980, 1989; Fodor et al. 1983; Kis, Balogh 2013).

In the Late Pliocene the foothill surfaces of the Mesozoic limestone mountains began to be dissected by erosional valleys directed towards the incising Danube Valley. In the Pleistocene landslides reshaped the slopes of north-directed valleys (Scharek et al. 2000; Ruszkiczay, Rüdiger et al. 2015). Active landslides are still found along the Danube Valley and endanger settlements there. In 2010 the built-up area of Dunaszentmiklós was affected by a both extensive and destructive landslide in Pleistocene slope deposits.

Recently, a GIS-based geostatistical analysis has also been made (Gerzsenyi, Albert 2018). Based on the National Landslides Cadastre (NLC) and from a Digital Elevation Model a landslide hazard map was created using a 'likelihood ratio function model' (Chung 2005) with elevation, slope, aspect, and categorized geological features as predictor variables. The model compares the distribution of variables in the landslide and non-landslide areas and identifies landslide hazard on similarity basis.

8.3.3 Movements of the high bluffs along the Danube

Along the Mezőföld loess region the undercutting by the Danube has resulted in a continuous westward reallocation of the loess bluff. From a detailed reconstruction of Roman fortresses (castra) along the Pannonian limes (Visy 1989), first of all that of the most important castrum, Intercisa (at the present-day Dunaújváros), the rate of bluff retreat can be estimated at 40-50 m over ca 2000 years (Lóczy et al. 1989).

Bluff instabilities are still typical on the right bank of the Hungarian Danube section (Balogh, Schweitzer 2011). One of the key sections of is south of Budapest at Kulcs (Balogh et al. 2014). In the last decades a reactivation of processes is observed. The movements are explained by the accumulation of pressurized confined groundwater percolating from the loess sequence in the heaps of former slides. The situation is aggravated by the prolonged high water stages of the Danube and the ensuing rapid drop in water levels. The lubricating effect ensures almost continues movement over the slip plane, which is located in red clays below the loess sequence. The clay beds dip towards the river and reach below the riverbed.

The old village of the neighbouring Rácalmás was built on fossil landslide heaps. The loess bluffs here are 5-35 m high and have accumulations of fossil landslides at their bases (Balogh et al. 2014). In the series of loess and loess-like deposits susceptible to piping movements can reactivate. This happened in 2003 with damage to roads, buildings and utilities. The triggering mechanism was water saturation due to a burst pipe. Root growth of trees on the bluff also add to instability. During high water stages the Danube has an undercutting effect even today (Szalai et al. 2013).

Groundwater springs significantly contribute to the generation of movements (Babák et al. 2013, Balogh et al. 2014). The detection of buried valleys allows the reconstruction of the main paths of groundwater flow (Schweitzer et al. 2011). In undisturbed stratification no concentrated outflow of groundwater occurs but seepage is uniformly distributed over the bluff surface. However, where extensive tongues of landslides hinder outflow, groundwater flow impounded in sand beds may raise the groundwater table up to top of the debris slope, where springs begin to issue. In wet periods the loess becomes oversaturated next to the springs and mudflows are generated.

Since 2006 mass movements recurred regularly along the southern section of the Danubian bluffs. At Dunaszekcső up to 20% of the Castle Hill was destroyed (Újvári et al. 2009, Bugya et al. 2011). In February 2008 along a 222-m-long failure front 0.3 million m^3 of material moved towards the Danube. In spring 2011 vertical displacements of 40 cm, indicating the initial phase of a new movement, were measured by geodetic and GPS surveying (Bányai et al. 2013). The instability of the Castle Hill is due to the Pleistocene loess/paleosol sequence overlying Upper Miocene lacustrine sediments. At Dunaszekcső in the ca. 57-m thick series loess is intercalated by 14 paleosol horizons and one sand bed (Kovács et al. 2015). Although training walls and groynes have been built during regulation measures to divert the current away from bank sections, the river intensively undercuts the slopes during each flood event. In addition, the leakage of a water tank in the background also contributed to the wetting of loess horizons.

8.3.4 Riverbank slumps along the Lower Tisza

Particularly high rates and diverse types of bank erosion are presented from the Hungarian section of the Tisza River, between Csongrád and Mártély (Kis, Lóczy 2018). In the mechanisms and types of mass movements along the riverbank natural geological (tectonic control, sedimentological buildup of banks and fluvial landforms) and hydrological (river regime and groundwater dynamics) factors are locally of equal significance.

Riverbank alluvial sequences are composed of clay, silt and sand layers. In this case, however, dust deposition took place on wet ground in the Pleistocene and the so-called 'lowland loess' has a higher (swelling) clay content than in the hills (Hernesz et al. 2015). The sedimentological properties of banks explain the differences between landslides along the Danube and Tisza rivers. In addition, Pannonian blue-green anoxic clays also function as slip planes.

In the most recent interval of bank erosion, in May 2013, the drop of water level on the Tisza happened at a record rate (6 m decrease within 8 days), reverting groundwater flow direction and inducing bank instabilities. The tree vegetation in the riparian zone also contributed to bank collapses under the given conditions. Major displacements of bank material were observed at 13 sites (Kis et al. 2014).

A recent study (Kis, Lóczy 2018) used the Bank Erosion Hazard Index (BEHI, Rosgen 2008) to identify sections where bank protection is desirable in contrast to other sections where natural conditions should be maintained for ecological purposes.

8.3.5 Micromorphological processes on loess bluffs

Steep walls of friable loess can show remarkable rates of retreat without mass movements proper. The processes are related to the seasonal wetting of wall surfaces (Boros, L. 1994). Autumn and winter rainfalls lead to the wetting of soils and unconsolidated deposits down to 40-60 cm. When moisture content reaches 15-18%, granular disintegration starts and continues to 20-28% moisture content, where the process is most intense. Between 28% and 38% cohesion stabilizes the wall, but with 38-40% moisture content saturation becomes so strong that solifluction ensues. Winter temperatures (frost conditions) also influence weathering processes. With moisture contents above 20-25% ice needles contribute to bluff retreat, particularly on the walls of hollow roads, which are abundant in vineyards.

8.3.6 Block slides along the margins of mountains of volcanic origin

From the mountains of volcanic origin in North Hungary landslide landforms had been described only occasionally before the 1980s (e.g. Székely 1961, Láng 1967). It was first evidenced for the slopes of the basalt-capped hills surrounding the Tapolca Basin that basalt blocks of the same K/Ar dating occur at different levels (Borsy et al. 1984). Then more and more instances were identified where in the marginal zones, fossil caldera edges and along valleys incised down to the bedrock landslides developed (Szabó 1996). The slip planes were weathered tuffs or clayey sediments underlying lava blocks.

Among the Miocene stratovolcanic edifices, the Mátra Mountains (with highest point of Hungary, 1014 m) provides good examples of landslides (Dávid 1992), which mostly occurred in areas where Tertiary friable sediments are overlain by tuffite beds and are elevated above the local base level. Since their features are fossil but still clearly detectable, landslides must have played an important part in the geomorphic evolution of mountain slopes during the Pleistocene, when relative relief intensified and the lubrication of deformable layers was common by meltwater infiltration.

In the northern foreland of the mountains (Mátralába) grey calcareous clays with intercalations of sands ('Schlier') dominate. In this area the cementation of sediments and the higher proportion of coarse fraction (sands, silts) usually prevents sliding. But the stratovolcanic structure means that compact layers are intercalated with those which have an outward dip and are liable to function as slip planes. Such a formation is the dacitic tuff of up to 100 m thickness, the clay content of which locally enriched to 13% by weathering.

The recent landslides in the mountains of volcanic origin are mostly caused by human interventions (road construction, undermining, irresponsible settlement development). The disastrous movements in the Tokaj Mountains, at Hollóháza, in spring 1999 resulted from housing development (despite warnings) on landslide-prone slopes (Zelenka, Trauer 1999; Szabó 2004). The strongly altered rhyolite tuff alternates with marine clays. When saturated, the tuffs become liable to sliding. Andesitic rocks in the basement weathered to bentonite and slides took place on their surfaces.

8.3.7 Spoil heaps and undermined areas

In the mining areas of Hungary (now mostly abandoned) diverse landform assemblages have evolved. In the Borsod coal-mining district numerous spoil heaps were accumulated, where the boundary between in situ and upheaped material is a potential slip plane (Sütő et al. 2016). The conical spoil heaps are 20-50 m high. On their 30-45° slopes mantle slides developed with tongues of 4-8 m length and 4-7 m width.

Spontaneous combustion in spoil heaps promotes their compaction and disintegration. The frost cracks dissect blocks and a laminar structure in the heap leads to failure scarps. The measurement carried out on failure walls (Sütő et al. 2010) indicate that the attenuation of movements strongly depends on weather conditions, the intensity of spring snowmelt and extraordinary rainfall events. The rate of movements amounts to 0.5 m per month.

8.4 Conclusions

The mass movements recorded in Hungary show a great diversity. In their overall spatial distribution, topography and geological buildup are the predominant factor. The overwhelming majority of movements are concentrated in Transdanubian and in the North Hungarian Mountain Range, primarily along the major river valleys. A fourth of the landslides are rotational slumps and a fifth are sliced slides. At almost half of the inventoried sites active movements were recorded and less than a fifth of them can be regarded fully or partially remediated. This proportion shows the important contribution of mass movements to land degradation.

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9. Soil sealing

Ádám KERTÉSZ[1]

9.1 Introduction

Soil sealing means covering the soil with building materials so that the connection between the soil and the atmosphere, hydrosphere and biosphere ceases to exist, with other words the land used for agriculture, forestry or simply for rural purposes will be taken into the built environment. The development of settlements, industry, transportation, infrastructure etc. requires more and more land surface, i.e. it consumes land and as a consequence, natural, semi-natural and rural land disappears will be converted to sealed surfaces, roads, buildings, industry plants etc.

According to FAO/ISRIC (1990) the term 'sealing' is internationally used in soil science for describing the effect of soil crusting. The European Commission Task Group on Soil Sealing, Soils in Urban Areas, Land Use and Land Use Planning (Burghardt et al. 2004) identifies three ways of sealing:

1. Definition by systems approach: "Soil sealing is the separation of soils by layers and other bodies (consisting of totally or partly impermeable material) from other compartments of the ecosystem, such as the biosphere, atmosphere, hydrosphere, anthroposphere and other parts of the pedosphere.

2. A definition following a purpose-related approach: Soil sealing is the covering of the soil surface with an impervious material, or the changing of its nature so that the soil becomes impermeable, so that the soil is no longer able to perform the range of functions associated with it.

3. Soil sealing, including natural characteristics: Changing the nature of the soil so that it behaves as an impermeable medium. This definition includes compaction of soils. Compaction of soils or subsoils may affect larger areas than the sealing as defined in definition (2)."

Burghardt (1993) distinguishes four types of soil sealing: (1) total surface sealing by road-metals and buildings; (2) partial sealing by pavements; (3) subsurface sealing of underground car parks covered by a soil layer, and the interruption of material and energy flow between the environmental compartments; (4) vertical sealing by walls exposed by construction in the soil.

The area covered by impermeable material is defined as sealed surface so it may not be identical with the area of e.g. settlements. This will be shown on the example of Germany. Statistical data give the values of the areas used for settlements, traffic and other types of sealed land use (e.g. recreation areas, cemeteries). These areas covered 12.8% of the area of Germany in 2004 whereas the sealed area of Germany was about 6.3% (Burghardt 2006).

It is obvious that soil the sealing of soils has harmful effects on ecosystems and

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generally on the environment. The loss of soils covered previously by natural, or semi-natural vegetation, or used for plant protection is a negative phenomenon from the aspect of ecosystem services. The harmful effects include the change of the hydrological properties like evaporation, runoff, the change of climate, especially microclimate. The sealed surfaces are taken out from the processes of the exchanges of water, energy and gases and as a consequence of this an increasing pressure is being exerted on adjacent, non-sealed areas. The negative effects include habitat and plant production loss, increased flood, pollution and health risks as well as higher social costs (Scalenghe, Ajmone Marsan 2009).

It is interesting, however, that the sealing of the soil is not always connected with landscape degradation and this is a good example of the difference between land (soil) and landscape degradation. Sealed surfaces providing the base, the foundation of nice building in the landscape, e.g. a castle, or even a whole settlement can represent an important and high aesthetical value in a particular area.

9.2 Soil sealing in Hungary

Table 1 shows the percentage of sealed areas in Hungary in 2015. The total sealed area in 2015 was higher, than in 2012, i.e. 3.975% of the country area. The area of sealed surfaces between 30-60% covers 2,1% of the country area and 52.8% of all sealed areas.

The percentage of sealed surfaces is presented in Figure 1. According to EEA data (European Environment Agency 2017) the percentage of sealed areas in Hungary in 2012 was 3.21%, in 2009 only 3.17 pointing to an increase of almost 10% in four years. Figure 1 shows the degree of soil sealing in Hungary. The map was compiled form Comparing the data of Hungary with those of Europe on the basis of the above EEA data the following countries should be mentioned. Small but highly developed countries like the Netherlands (8.07), Belgium (7.56), Lichtenstein (6.28), Luxembourg (5.18%) and Germany (5.17) dispose of extremely high values. The island of Malta, a small country with a relatively small country area has an outstanding value of 16.27.

Table 1. The degree of soil sealing in Hungary based on COPERNICUS 2015 data

Degree of soil sealing (%)	Area (km^2)	Area (%)
0	89 309.872	96.025
1-10	180.476	0.194
11-20	443.015	0.476
21-30	725.704	0.780
31-40	857.296	0.922
41-50	696.441	0.749
51-60	395.289	0.425
61-70	190.788	0.205
71-80	103.290	0.111
81-90	62.220	0.067
91-100	42.150	0.045

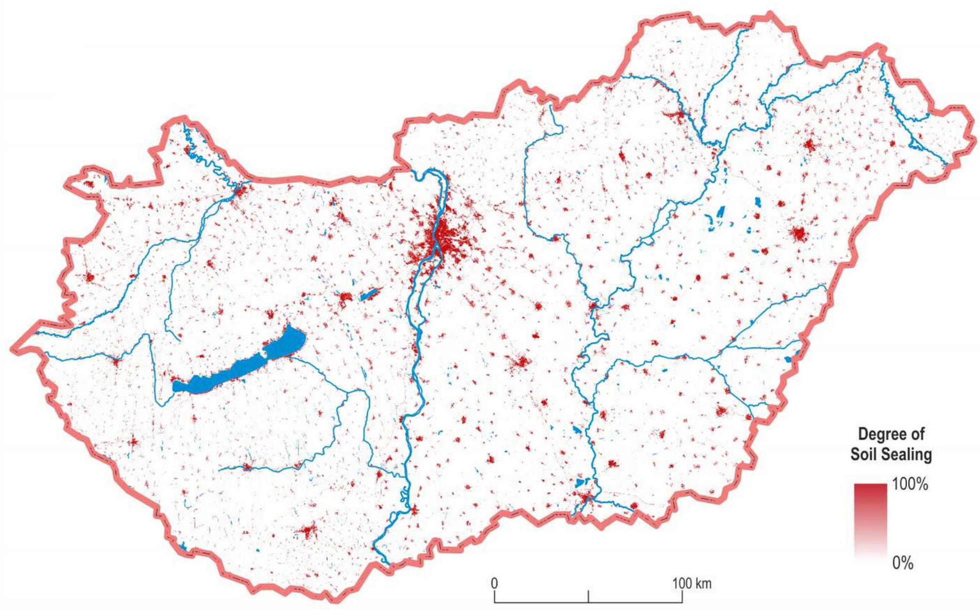

Fig. 1. Soil sealing map of Hungary

The sealing percentage values of highly developed countries like the U.K. (3.54), Denmark (3.62), Switzerland (3.36) and France (2.84) may have relatively low values. The average of the EU 39 is 2.87%. It is obvious that the main controlling factor of the percentage of sealed surfaces is population density.

Figure 2 shows the relationship of soil sealing and population density in the case of Budapest. 59.6% is the average sealing degree. Some examples from Europe: London 42.5%, Berlin 47.5%, Amsterdam 44.9%, Copenhagen 45.9%, Brussels 31.0% and Stockholm only 22.4%.

The degree of soil sealing in Hungary is not very high but it is accelerating (see the rate between 2009 and 2011 above). The reason for a still acceptable percentage is the high proportion of areas used for agriculture and forestry and the wetlands and other natural or semi-natural vegetation types like in the cases of France and Denmark (see above data).

9.3 Wounds in the landscape

As already mentioned sealed surfaces may hold nice landscape elements but the so-called wound (scars) cut in the surface decrease the aesthetical value of the landscape. Wounds are defined similarly to wounds of the human body, i.e. injuries, cuttings, holes, i.e. smaller or bigger areas where the surface is stripped, hurt and not continuous any more. As soon as the vegetation starts to develop and it is spread out on a wound and it takes over the wound is classified under the appropriate vegetation cover category.

Temporary landscape scars (among others, those caused by off-road driving) were not taken into account, partly because of the scale of the investigation and partly because they disappear sooner or later.

Construction areas can be territories under construction development, earthworks, soil or bedrock excavations. Quarries and mineral extraction sites are

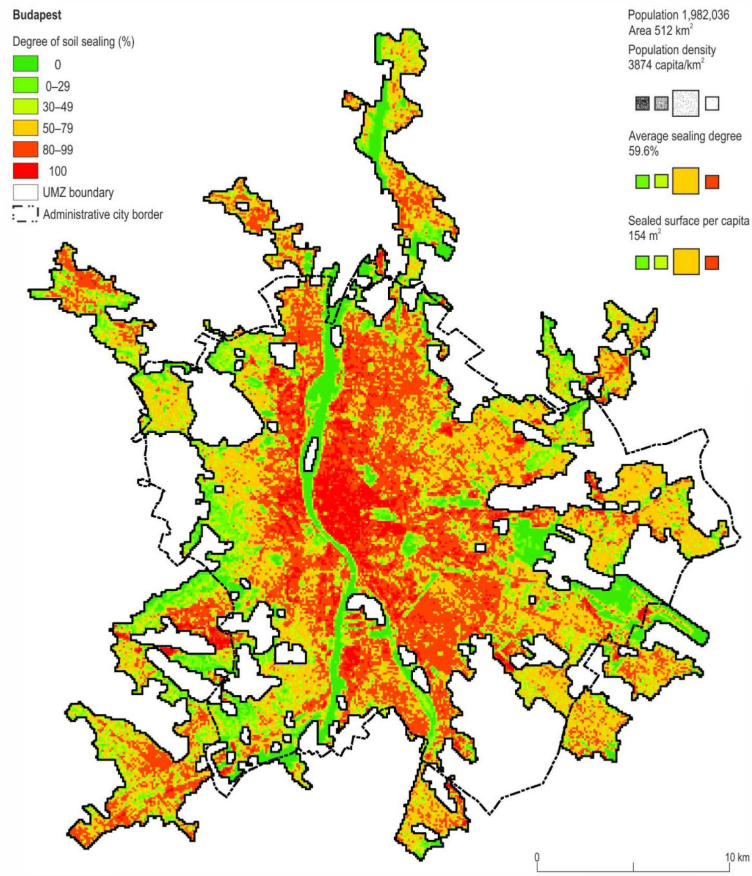

Fig. 2. Soil sealing and population density in Budapest in 2011.
European Environment Agency (https://www.eea.europa.eu/data-and-maps/figures/soil-sealing-in-the-capitals) 2011.

similar to several construction sites but if there is a confusion it is not relevant from the aspect of landscape wounds.

Two thirds of the country area are covered by loose sediments in Hungary and so it is easy to make temporary or permanent wounds in the landscape.

Functioning and abandoned gravel pits accompany a relatively bright stipe along the rivers as the Pleistocene terrace deposits offer good building materials. Sand pits were typical forms in the outer areas of settlements in the old times, i.e. up to roughly 50 years ago when each village or settlement had their own pits for construction.

The conclusion is that there are realtively few wounds on the surface of Hungary ruining the aesthetical value of the landscape.

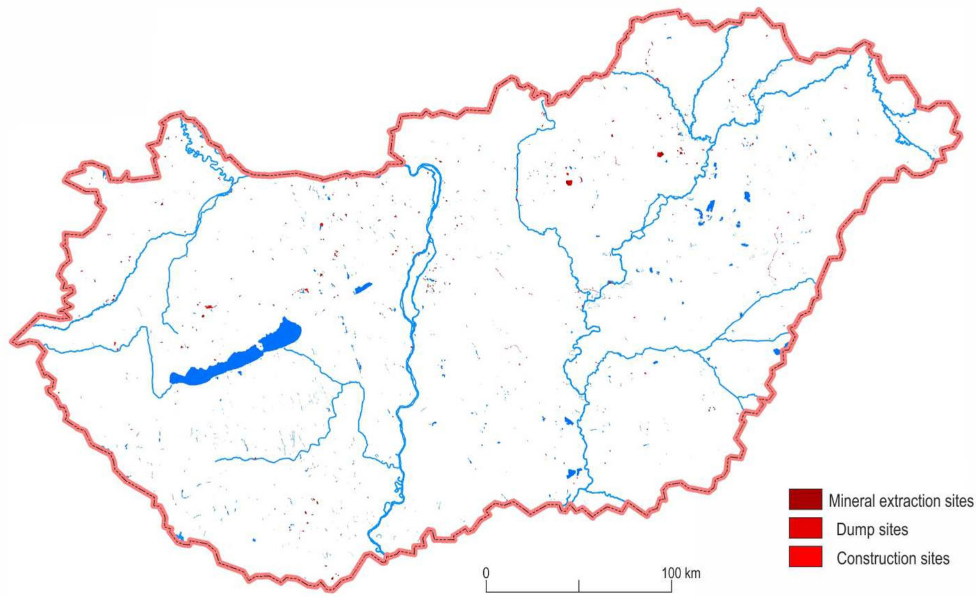

Fig. 3. Wounds in the landscape in Hungary

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10. Floods

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10.1 Introduction

Floods are major sources of short-term land degradation in lowlands. In soils redox potential and aggregate stability are closely related parameters. Therefore, under anoxic conditions soil quality is reduced. Climate change is predicted to bring about both more frequent droughts and excessive rainfall events resulting in unpredictable runoff and river water regimes in Hungary. Excess water hazard from raised groundwater levels is found to affect much larger areas than previously thought. Recently strongly localized cloudbursts have occurred and point to the increasing significance of flash floods in Hungary.

In soils which are often under water for days or weeks, oxygen deficit, i.e. reductive conditions affect the chemistry of the soil-water system and lead to soil disaggregation (De-Campos et al. 2009). Since soil aggregation is an important factor of the physico-chemical state of the soil and essential for soil quality, disaggregation reduces both soil quality and crop production. A strong inverse correlation was found between changes in the redox potential and aggregate stability. Cultivated soils are more sensitive to reducing conditions and unfavourable trends in aggregate stability might be irreversible. Soil pores are clogged and the chemistry of the soil solution deteriorates.

The spatial pattern of riparian habitats is generated by the natural alternation of floods and droughts. Meso-scale habitats are controlled by landforms (bars, natural levees, side and abandoned channels – Fryirs, Brierley 2013) and riverine vegetation (Steiger et al. 2005). River channelisation and widespread agricultural utilization created 'protected' (topographical or morphological) floodplains, i.e. areas beyond flood-control dykes, led to gradual desiccation, the loss of wetlands and reduced landscape diversity (Somogyi ed. 2000).

For the purposes of flood control, the moderation of flood peaks and sedimentation as well as floodwater retention are ecosystem functions of primary significance (Geilen et al. 2004). With droughts becoming more and more common throughout Central Europe, Natural Water Retention Measures (NWRM) become necessary parallel with flood control. They are multi-purpose interventions with the aims of protecting water resources, restoring or maintaining ecosystems as well as the close-to-natural state of water bodies (Schwarz 2014).

Floods of high magnitude and low frequency, however, should not be fully dispensed with since they are crucial to maintain riparian/floodplain habitat diversity (Hooper et al. 2005). Even 'flood pulses' of low magnitude and short duration (Tockner et al. 2000) can change floodplain habitats. Groundwater–surface

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water interactions should be kept under control to ensure ecosystem services in the active floodplain (Jones, Holmes 1996; Jones, Mulholland 2000).

10.2 Spatial and temporal aspects of flood hazard

The whole of Hungary belongs to the catchment of the Danube. There is a marked contrast between the hydrogeographical conditions in the catchment of the Danube and its major left-bank tributary, the Tisza River, but extensive areas are highly exposed to flood hazard (Zsuffa 1999) and, consequently, flood control has ever been a central task of Hungarian water management policy (Kovács 1979; Somlyódy 2000).

Overall flood hazard in Hungary is differently interpreted in water management literature (Lóczy 2010). Recent assessments (e.g. Szlávik 2000, 2001; Mezősi 2008, 2011) point out that while the regime of the Danube is controlled by snowmelt in the Eastern Alps, snowmelt tends to occur belated and more and more often overlap with the traditionally predominant early summer flood waves (Jeneiová et al. 2016). Floods in spring and early summer are of ever longer duration (exceptionally even last for four months a year), posing an increasing threat to the stability of flood-control dykes.

The Danube has no significant tributaries along its Hungarian section. In contrast, the flood pattern of the Tisza River is under the influence of numerous major tributaries (Andó 2002). Although both rivers share the same flood peaks, the floods of the Tisza are different in several respects (Vágás 1982). The tributaries differ in their slopes and, consequently, in the duration of flood waves, which are often superimposed on the flood waves of the trunk river. The backwater effect of the Tisza causes inundations along dozens of kilometres of lengths of tributaries on their lowermost sections. Rearranging precipitation patterns may even cause winter floods. The basic reason for the floods of the Tisza is channelization between too closely spaced dykes, which hinders channel adjustment (Ihrig 1973; Schweitzer 2001).

The level of design flood is defined in the Government Decree # 2006/1973 for various return periods (Hankó et al. 2003):

- along main flood control dykes: 100 years;
- in urban and industrial areas: 120-150 years;
- in priority areas (e.g. near the capital city): 1000 years and
- for less valuable protected areas: 60-80 years.

Almost a quarter of the territory of Hungary (93,030 km^2), 21,248 km^2 (22.8%), mostly along the Tisza and the Danube, are endangered by the 100-year return period floods (Szlávik 2000). Due to river regulations 23% of this area is protected from inundation. In geomorphological floodplains almost 2.5 million people live in 700 settlements. A large percentage of national wealth (32% of railways, 15% of public roads, 1.7 million ha of agricultural land) are found in floodplains. However, along small watercourses another almost 10,000 km^2 of floodplain (10% of total area) is also threatened. The survey of the precise extension of such areas started in 2015.

Since drainage density is a characteristic property of physical geographical units, flood hazard can be represented by the microregions of Hungary, based on the frequency of inundation of the active floodplain in the period 1990-2015 (Figure 1).

In spite of great efforts to improve the Hungarian flood control systems (of more than 4200 km total length of primary defence lines), some environmental factors increase flood hazard. Flood discharges

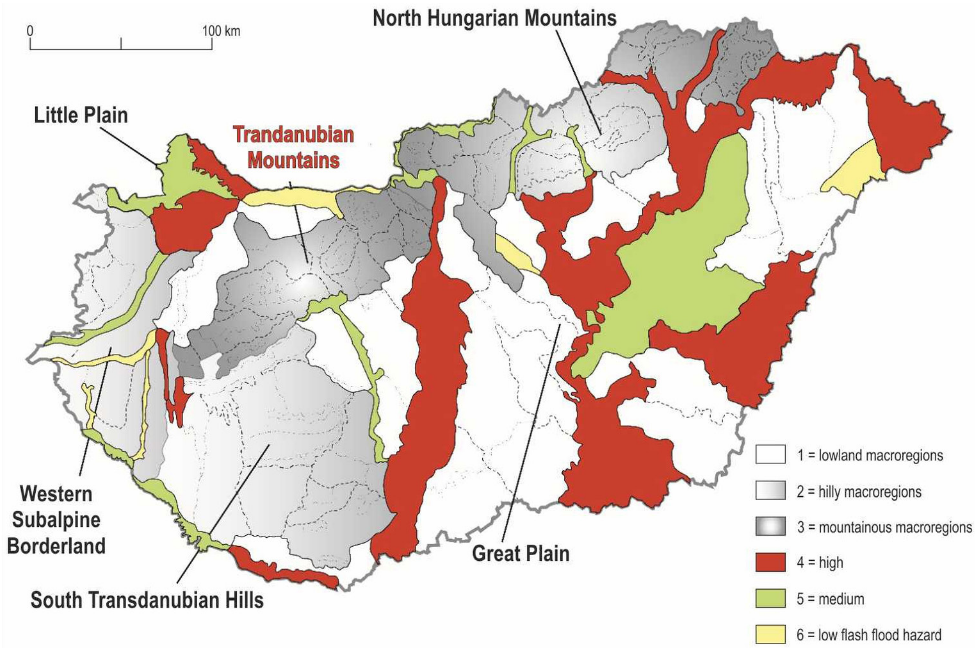

Fig. 1. Assessment of riverine flood hazard by the microregions of Hungary (by Lóczy from data by VITUKI 1990-2015). Continuous lines indicate the borders of macroregions, dashed lines the borders of units lower in the hierarchy (meso- and microregions). 1 = lowland macroregions; 2 = hilly macroregions; 3 = mountainous macroregions; 4 = microregions with extensive active floodplain sections (inundated on more than eight occasions in the studied interval); 5 = microregions with floodplains affected by the locally defined design flood (floodplains inundated on four to seven occasions); 6 = other potentially affected microregions (floodplains inundated on less than four occasions)

are growing due to land use and climate changes in the upper catchments of major rivers. Floodplain sedimentation reduces the capacity of floodways (Schweitzer 2001; Kiss, Fejes 2000; Kiss et al. 2002; Gábris et al. 2002; Varga et al. 2018). The impact of drought years in recent decades is detrimental on the (sometimes rather neglected) conditions of flood-control dykes.

Floods are not necessarily generated by runoff in the mountain frame of the Carpathian Basin. In May 2010 a Mediterranean cyclone produced excessive rainfalls (amounts locally exceeding 300 mm per month, i.e. three- or four-fold the monthly average amount) in the Carpathian Basin. Critical high-water levels resulted along some medium-size rivers like the Kapos in Southwest Hungary (Figure 2) and the Sajó, Zagyva and small streams in Northeast Hungary. Similar situations have repeatedly occurred in recent years.

In 2006 the Hungarian government passed legislation for preventing housing development in so-called "high-water channel" areas (i.e. the channel corresponding to the design flood level or to the highest water level recorded to date – Government Decree 2006). The legislation ensures the priority of flood control considerations in land use planning.

Fig. 2. Flood defence on the Kapos River at Döbrököz, May 2010 (Photo by Lóczy)

10.3 Excess water hazard

Excess water is another source of land degradation as it also inhibits crop root growth through creating prolonged reductive conditions in the root zone. In the recent interpretation excess water is rather widely conceived (Pálfai 2001; Szatmári, van Leeuwen eds. 2013). In addition to groundwater levels raised on the floodplains of major rivers during flood stages, any other inundation in lowland areas is included. According to a recent definition excess water originates from rainfall or snowmelt, covers extensive lowland areas temporarily and causes soil saturation. It is still debated whether soil saturation necessarily means surface inundation (Rakonczai et al. 2011).

Towards the end of the 20th century, excess water hazard has been observed to increase dramatically (Pálfai 2000). The record value of 600,000 ha inundated area (in 1942) was approached again in 1999 (440,000 ha). The May 2010 rainfalls caused excess water inundations over 167,000 hectares area. Human constructions in the landscape and the neglect of land drainage systems contribute to more frequent inundations in the Great Plain (Szatmári, van Leeuwen, B. eds 2013). Locally it is the flood-control dykes themselves which hinder the drainage of excess water back to the river channel (Pálfai 1988).

The map of excess water hazard was constructed using topographic, geological, pedological, groundwater depth and land use data (Pálfai 1994). The map (processed for Figure 3) identifies four classes:

- serious hazard, where inundations regularly recur in wet years;
- medium hazard, where one-time floodways and backswamps and swamps enclosed between alluvial fans are exposed to accumulation of rainwater or groundwater rising to the surface;
- moderate hazard, where natural levees in floodplains and lower sections of alluvial fans are affected and
- no hazard areas, where high relief or permeable surface deposits (sands) on

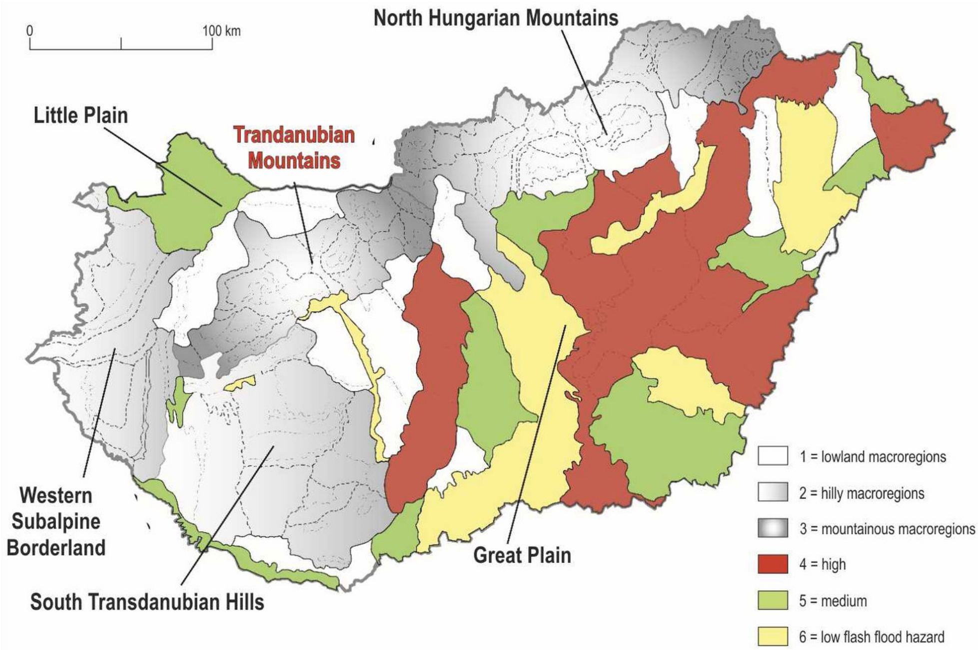

Fig. 3. Excess water hazard in the Great Hungarian Plain (generalized after Pálfai 2000). For 1 to 3 see Fig. 1. 4 = severe; 5 = medium; 6 = moderate excess water hazard

flat surfaces prevent inundation.

The first three categories make up more than 2 million hectares in Hungary, i.e. one-third of the agricultural area. Naturally, few microregions are threatened by excess water in their entirety but the map indicates microregions where significant portions are affected.

10.4 Flash flood hazard

In the 21st century disastrous floods happened in highly restricted sections of mountainous and hilly catchments in various parts of Hungary (Czigány et al. 2013). This has given impetus to flash flood research (Czigány et al. 2009; Lóczy et al. 2011). On the occasions when convective rainfall systems reach the Carpathian Basin, intensity can amount to 100 mm within 1-3 hours. The aim was to parametrize a model which is capable of a rapid screening of the areal distribution of this hazard in Hungary. The idea is that passive ground conditions (relief, soil permeability, catchment geomorphology, land use, vegetation cover – Hegedűs et al. 2013) are equally important in the generation of flash floods as the active triggering factor (usually intense and prolonged rainfall). Since the large proportion of sealed surfaces in towns inhibit infiltration and induce rapid runoff, urban floods also belong here in a broader sense (Ronczyk et al. 2015). With a high-resolution DEM, the location of catchments prone to flash flood hazard can be identified (Figure 4.).

As increasing evidence points to climate change (i.e. the growing frequency of extreme rainfall events), flash floods have been recognized as an increasing environmental hazard in Hungary. Although both spatial and seasonal distribution of this hazard is uneven, virtually all mountainous and hilly

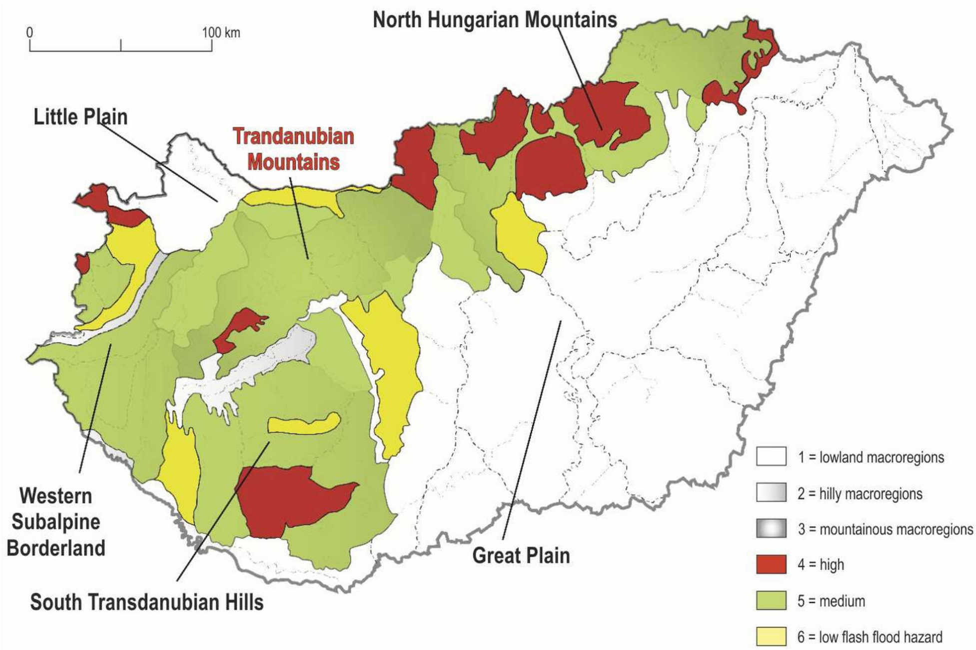

Fig. 4. Flash flood hazard (after Czigány et al. 2009). For 1-3= see Fig; 1. 4 = high; 5 = medium; 6 = low flash flood hazard

microregions of Hungary are under threat (Figure 4). The variation in the extent of hazard, however, depends on relief and runoff conditions. Closed basins, the forelands of steep margins of mountains and hills, entrances to narrow valleys are some of the typical locations where flash floods can be expected.

10.5 Flood control concepts

The 'obvious' solution in flood control is the constant raising of dyke heights – an engineering (structural) response, often very costly. Environmentally more acceptable responses to increased riverine flood hazard – particularly on the Tisza River – are envisioned in several ways (Mezősi 2008):

- through amending water retention in the headwater areas (outside the borders of Hungary);
- through enhancing the conveyance capacity of floodways;
- through river impoundment beyond dams;
- through constructing smaller emergency reservoirs (used as meadows or pastures in flood-free periods) along the trunk river and its major tributaries.

The exploitation of the water retention capacities of oxbow lakes in floodplains can be an ecologically favourable solution (Babka et al. 2017; Lóczy et al. 2019).

Along the Tisza and tributaries emergency reservoirs are being built to prevent, restrict or (at least) delay the inundation of the morphological floodplain (Balogh 2012). through opening flood gates thee breaching of defence lines can be precluded. Along the Danube, the row of reservoirs of the Austrian river section and the Čunovo reservoir in Slovakia are capable of reducing (but not eliminating) flood hazard in Hungary (Zsuffa 1999). The development of monitoring and warning systems is a necessary precondition to avoid unexpected disasters.

10.6 Flood hazard along the Hungarian section of the Drava River

The river regime of the Drava (Lovász 1972, 1983), is equally influenced by snowmelt in the higher zones of the Alps (drained by the tributary Mura/Mur River), snowmelt in the eastern Alpine foreland and recurring Mediterranean cyclones causing a secondary peak in October or November.

Under pristine conditions, the Drava river was constantly changing its course creating a system of abandoned channels. During floods, only higher areas were free of inundation, a wide belt (ca 115,000 ha) along the river was waterlogged. From the 12th-13th centuries the Drava had two branches of approximately the same size. As a first evidence, a document from 1294 mentions regular flooding in the Ormánság region (Ihrig 1973). One of the worst of the Drava floods was recorded on 3 June 1770 and again on 5 November of the same year. There was a very poor harvest of cereals. At the end of the 18th century the Drava changed its course again. Villages had to be resettled on higher ground both in Croatia and Hungary (Petrić, Obadić 2007).

In 1812, 1814 and 1816 the Drava repeatedly flooded and the crop yields were poor again. The bridge of Barcs was so heavily damaged that it was impossible to import food from Hungary to Croatia.

Flow regulation on the lower Drava began at a relatively early date. Between 1730 to 1740, the landowners formed an association for the purposes of flood protection, building their first protective structures on the left river bank, between the villages Szabolcs and Dárda, which were extended and strengthened in 1770–1773. The most devastating flood occurred in 1827, when numerous villages were literally washed away.

Massive construction in the Drava River basin and on the river itself during the last centuries, as well as recent climate change and/or variability has caused many different and possibly dangerous changes to its hydrological and ecological regime (Bonacci, Oskoruš 2008).

By the beginning of the 20th century the essential structures of flood-control had been completed downstream of Barcs (Takács, Kern 2015). Although there have been several development projects on the Dráva dykes in recent years, the dyke system is not uniform and does not meet safety requirements along its whole length. The defence lines on the left bank of the Drava include the Drávaszabolcs section (earth embankments of 31,709 m length, continuation of the Croatian system) and the Drávasztára section (33,720 m), where embankments are 0.6 m lower on the average compared to required security level (1.2 m above the highest water stage of the river measured to date). The high bluffs make flood protection superfluous further upstream. Secondary defence lines (localization dykes) in the Drava floodplain only amount to a couple of kilometres.

The new regulation on floodway management planning (Government decree 83/2014 [14 March]) prescribes the rules for the precise delimitation of floodways (for the Lower Drava see Czigány et al. 2016), preparation and implementation of their management plan. The defence during recent floods on the Danube (June 2013) and on the Drava (November 2012, September 2014) justified the need for the decree.

10.7 Conclusions

Flow regulations could not eliminate flood hazard in Hungary. Although along the Tisza River there occurred not more than 23 major flood events until 2001, the floods in 1998, 1999 and 2001, were all 'extraordinary' within a short interval (Bakonyi 2010). This proves that riverine floods remained an essential part of the natural hydrological system in the Carpathian Basin.

Recently a steady rise in flood levels have been observed along the major rivers. This is primarily due to interactions between human activities on the catchment (deforestation, housing and infrastructural development, restriction of floodplain widths) and the direct and indirect impacts of climate change (inclination to more intensive drought and unpredictability of rainfall, discontinuous vegetation cover).

Under the conditions of changing climate, in addition to river floodplains, hill valleys with flash flood hazard and lowlands with excess water hazard have also to be surveyed and monitored. The adjustment of the population to inundation has been a common practice in the past and it is even more necessary in the future. The careful maintenance of flood-control dyke systems and probably the establishment of emergency reservoirs can alleviate riverine flood hazard. However, it is practically impossible to avoid inundations from excess water or flash floods induced by local cloudbursts, which may occur with an increased frequency in the future. Regulation on housing development and other forms of land use change has to be more rigorous and should be enforced without allowing for any exception.

As a consequence of river regulation and land drainage measures on the one hand and the impact of global climate change on the other, the alternation of floods and drought periods became typical of the environment of the Hungarian Drava floodplain. Extremities in water availability strongly effect the quality of life of the local population. Similarly to other rivers, on the Drava, too, the ecosystem services of diverse freshwater habitats have been significantly altered. Given their ecological importance, there is an urgent need for restoration of these habitats to prevent further land degradation in floodplains and to improve their ecosystem services.

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11. Landscape aesthetics

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11.1 Introduction

Landscape aesthetics, as a relatively new scientific topic is spreading nowadays due to the growing importance of anthropogenic influences effecting the landscapes. For the people, e.g. for the population of a settlement, the degradation of the landscape is manifested in the decay of the aesthetical value of their environment.

Research on landscape aesthetics started in the 1970's in the USA, Canada and the former Federal Republic of Germany (Eckbo 1975, Craick 1975, Bürgin et al. 1985). A practical handbook was prepared in the USA for forestry specialists and landscape architects on the preservation and evaluation of landscape values (U.S. Forest Service 1995). Rétvári (1986) carried out the first research on landscape aesthetics in Hungary. Quite a number of publications appeared on the topic the 2000's especially on its potential significance concerning recreation (Lóczy 2002; Kiss, Horváth 2003; Drexler et al. 2003; Szilassi 2003).

GIS based landscape aesthetical evaluation has become a generally applied method in the last decade (Wu et al. 2006, Huang 2015). The aesthetical value of a landscape can be assessed numerically by pixels. The results will be stored in database suitable to create maps, to estimate landscape potential. The results of data processing and analysis provide a good basis for decision making in an easily understandable way. A GIS-based country-wide landscape aesthetical analysis for Hungary has been carried out by Kollányi and Csemez (2006).

The aim of this study is to evaluate the current status of the landscape aesthetical value of Hungary by GIS methods.

11.2 Materials and methods

The difficulty of the evaluation of the aesthetics of a landscape can be expressed shortly by its subjectivity. Concepts, like that of the landscapes visual character can be defined more precisely: "the visual expression of spatial elements, structure and pattern in the landscape" (Ode et al. 2008) Beauty, aesthetics are, however, hardly definable terms with many personal aspects making an objective assessment very difficult. Because of these difficulties a baseline conception is needed to avoid subjectivity.

Our taste concerning natural beauty is influenced by many factors like ecological knowledge, economic self-interest or cultural identity (Wagner 2008). The rate of naturalness is fundamental and nowadays, due to global environmentalism

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(Guha 2000) it is more or less generally agreed that the carrier of beauty is a good principle to determine the baseline of the evaluation.

Landscapes less affected by human interventions received higher scores in the evaluation process. However, it is also evident that naturalness is not the only aspect determining beauty. The presence and rate of spectacular and diverse landscape elements area dealt with in the second stage of the evaluation. Diversity and richness of landscape elements can be expressed by the complexity of the landscape (Kaplan, Kaplan 1989). Vivid relief, forest cover and water surfaces were chosen as most determining elements of landscapes which are generally considered to raise the beauty of a landscape. Anthropogenic elements were also taken into account decreasing naturalness, thus the beauty of a landscape. Agricultural areas were evaluated using the landscape diversity map created during the landscape aesthetical analysis. Vineyards as anthropogenic but still positively considered elements were handled separately. Settlements were excluded from the evaluation.

For the creation of the map numerous free access raster and vector databases were used (CORINE land use database; SRTM raster surface model; Google Earth; Geocaching; OpenStreetMap; database of Nature 2000 areas; Hungarian National Ecological Network; UNESCO World Heritage Sites). Data management and analysis was carried out by ArcMap 10 and QGIS.F software packages. The raster database of the map was created in 30 m resolution in alignment with the SRTM raster digital surface model.

Database layers were processed and overlayed by different GIS methods. For the assessment both raster and vector data were applied. The ArcGis operations included weighted overlay, weighted sum, map algebra fuzzy overlay (fuzzy or, fuzzy sum) and buffering.

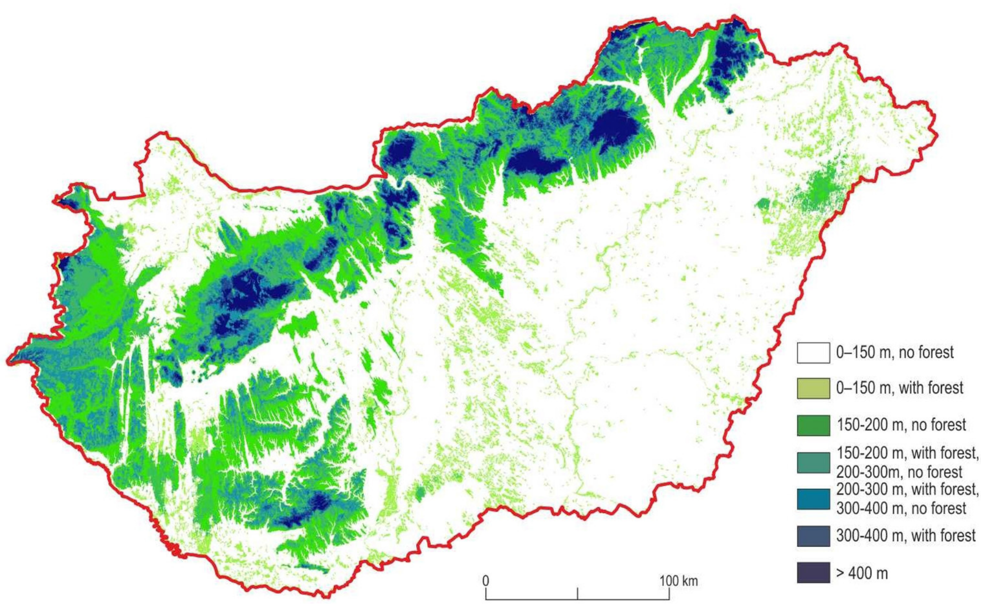

Fig. 1. Layer of relief and forests

11.3 GIS operations and results

11.3.1. Evaluation of landscape elements increasing landscape beauty

The evaluation of landscape elements increasing landscape beauty (coinciding practically with natural elements) consisted of the assessment of relief, forest cover, lakes and rivers, protected areas and vineyards.

Relief and forest cover are often strongly interrelated (except lowland forests). Relief, forest cover and surface waters are the most dominant landscape elements. Thus the first operation with ArcMap 10 was the weighted layering of these two elements. The forest cover layer was selected from the CORINE land cover database followed by rasterising. The relief layer was created by using the 30m resolution SRTM raster digital surface model. Relief data were classified by height: 0 = 0-150 m, 1 = 150-200 m, 3 = 200-300 m, 5 = 300-400 m, 6 = 400-600 m, 7 > 600 m. In the course of weighted layering, 60% weight was given to forest and 40% to relief. The results of this operation are shown in Figure 1.

As mentioned above, according to our concept the rate of naturalness determines the beauty of a landscape. Following this theory, protected areas play an important role in the landscape aesthetical evaluation assuming that areas in natural, or semi-natural condition are generally protected. For the layer of protected areas the Nature 2000 database and Hungarian National Ecological Network database were used. After rasterising the layers were summed. If the two types of protection overlapped, i.e. areas under multiple protection, they received higher scores: overlapped areas: 2; areas without overlapping: 1.

The layer of relief and forest cover and the layer of protected areas were summed (weighted summing (Figure 2). Protected areas received somewhat higher weights to decrease the relief-domination of the map and to raise the aesthetically valuable

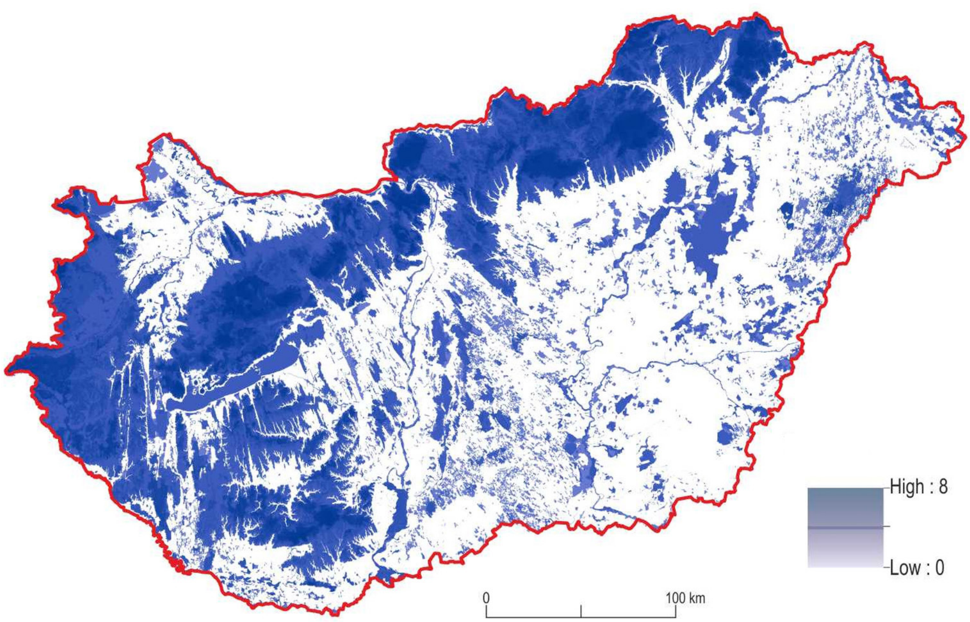

Fig. 2. Layer of relief, forests and protected areas (0-8: increasing aesthetic value)

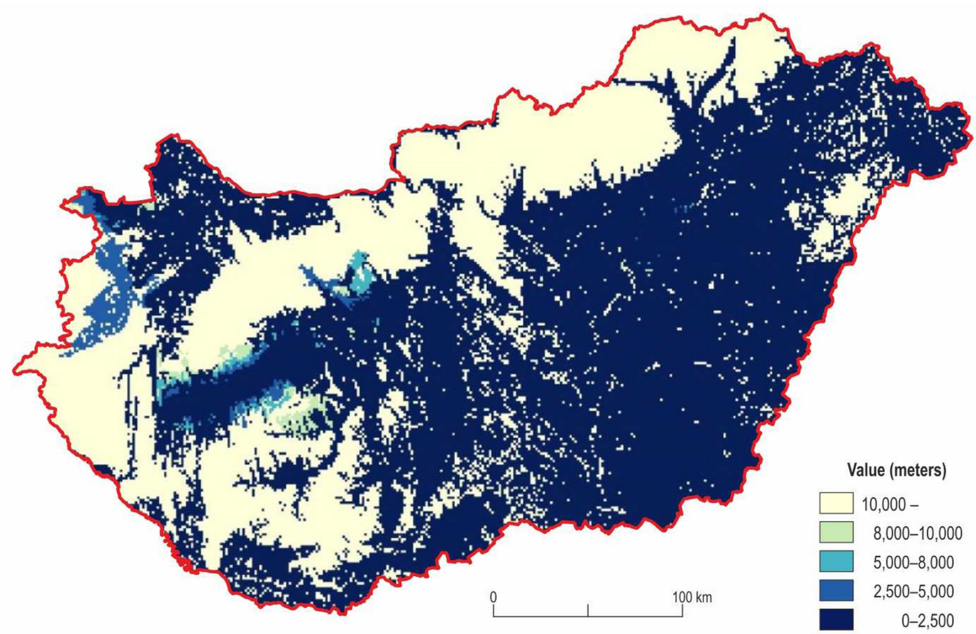

Fig. 3. Buffer analysis (visibility buffers) for the lakes Balaton, Velence and Fertő, applying the U. S. Forest Service (1995) method, taking relief and forests into account

lowland areas. The applied weights are as follows: layer of protected areas: 1, 2; layer of relief and forest cover: 1.

It can be observed that after adding the layer of protected areas, the areas with higher scores of the first map are highlighted again, i.e. the higher lying areas covered by forest. This result supports our decision about relief and forest cover as important natural landscape elements of naturalness and beauty. High biodiversity is characteristic for the protected areas in addition to their high landscape aesthetical value. Valuable natural or semi-natural areas of the lowlands which are evidently beautiful but even if maybe less spectacular, could be also distinguished.

The third dominant group of landscape elements is the group of surface waters. Lakes as vector-polygons and water courses (rivers and creeks) as vector-polygons and linear elements were treated technically separately.

Large water-surfaces are obviously of outstanding importance in respect of the touristic magnetism of the landscapes (Michalkó 2007). As the impressiveness of lakes increases with size they were classified in increasing order (1-6). Fuzzy overlay was applied for the layer of lakes and for the former layers. This approach visualizes the joint effect of the individual layers.

Buffer analysis was carried out to reveal the effect of the common presence of water bodies, forests and diverse relief on landscape aesthetics. The beauty of fascinating waters can be even more prominent if surrounded by hills, mountains, forests. This analysis was performed for the largest lakes of Hungary, for Lake Balaton, Lake Velencei and Lake Fertő (Figure 3).

Vineyards were taken out from agricultural areas because they are a significant component of Hungarian culture and of the Hungarian landscape.

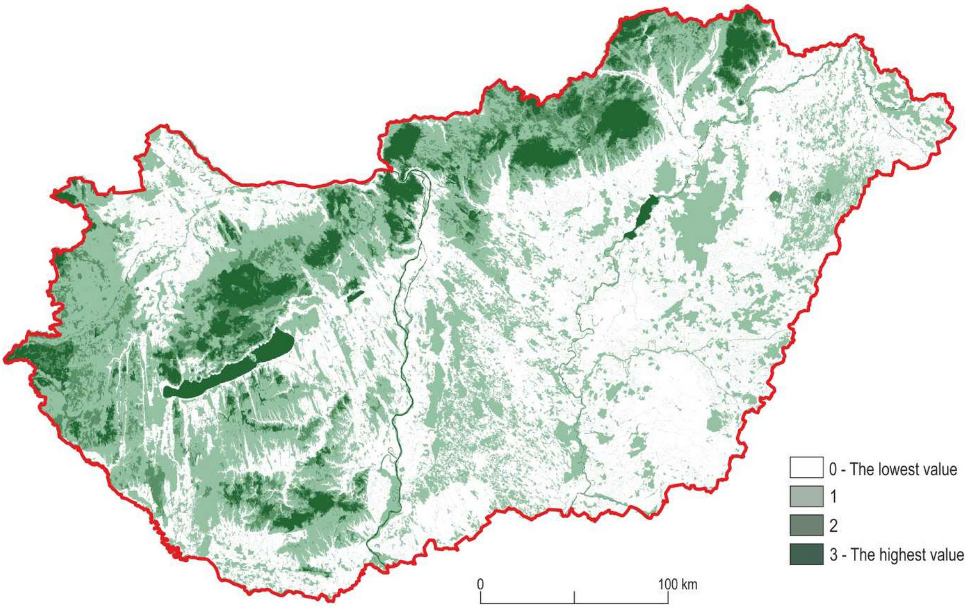

Fig. 4. Landscape aesthetic value of natural landscape elements

Hungarians consider vineyards as positively as natural areas without anthropogenic influences (Csima, Pádárné Török 2012). The layer of vineyards was added to the layers already used in the analysis.

The layer of watercourses was handled as a vector database containing both linear and polygonal elements. The linear elements were buffered with 20 m wide buffer zones on both sides followed by rasterization. Just like in the case of lakes, watercourses were also classified by size. The layer of watercourses was added to the former layers by fuzzy layering to highlight maximal values. The aesthetic value of natural landscape elements is shown in Figure 4.

11.4 Evaluation of artificial landscape elements

The evaluation of artificial landscape elements was a relatively simple process due to the character of these data. In addition to using the CORINE Land Cover 2012 data and Geocaching databases, some other digitized data were applied as well (e.g. solar power plants, outskirt shopping centres, high-tension power lines).

Working with a vector database point, linear and polygon elements were evaluated separately and rasterised. The classification and evaluation of artificial landscape elements were carried out according to their range and their negative or positive effect on the surrounding landscape.

The layer of artificial polygons was created the merge function after the classification based on range and effect of the elements (Figure 5).

The layer of artificial point-like elements (Figure 6) was produced by using the Geocatching databases. To indicate their effect in the landscape, point-like elements were buffered with 30, 50, 60 m wide buffer zones according to their size and height. The synthesis of the layers of polygons and

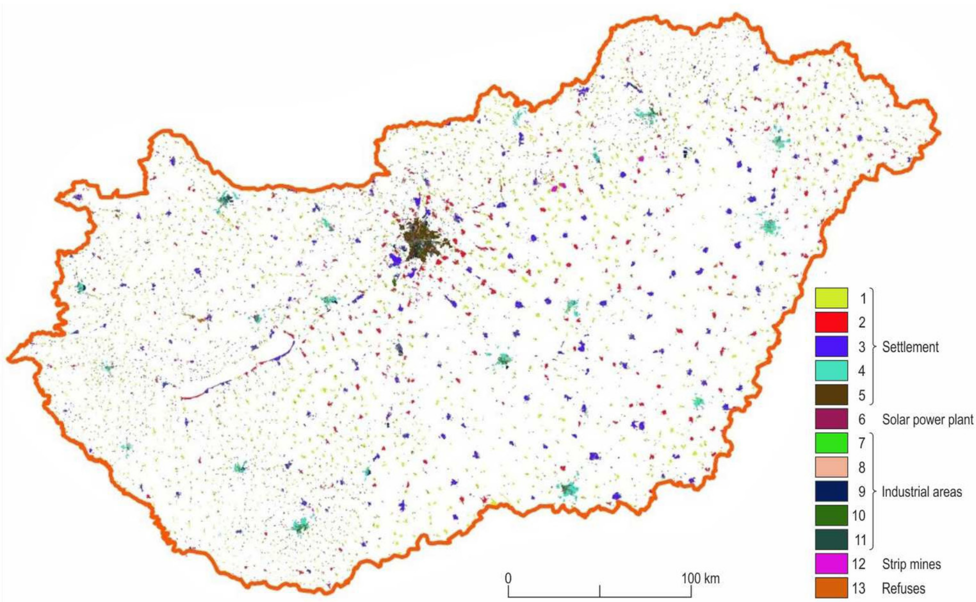

Fig. 5. Layer of artificial polygons

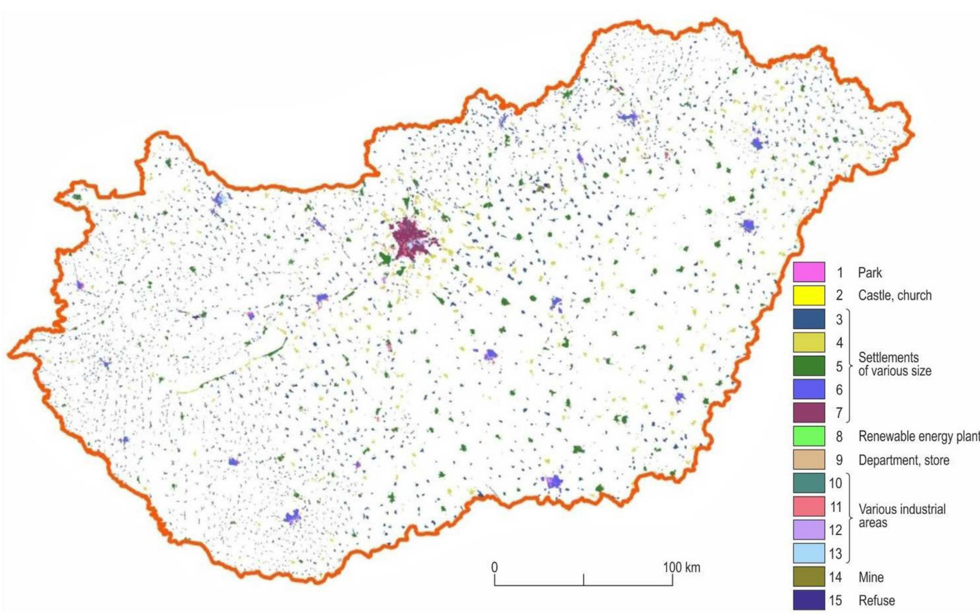

Fig. 6. Layer of artificial polygons and points

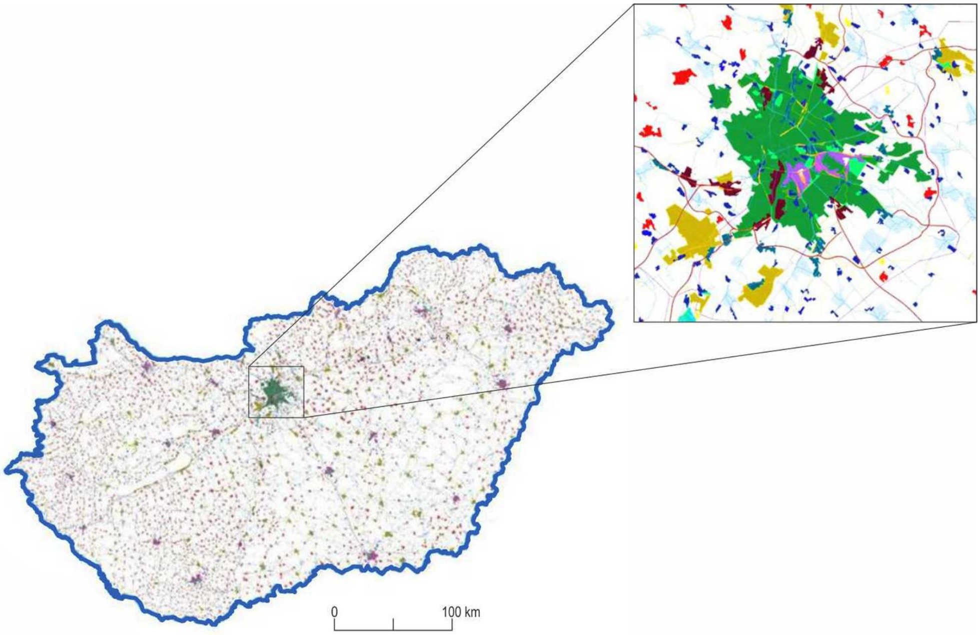

Fig. 7. Layer of artificial landscape elements

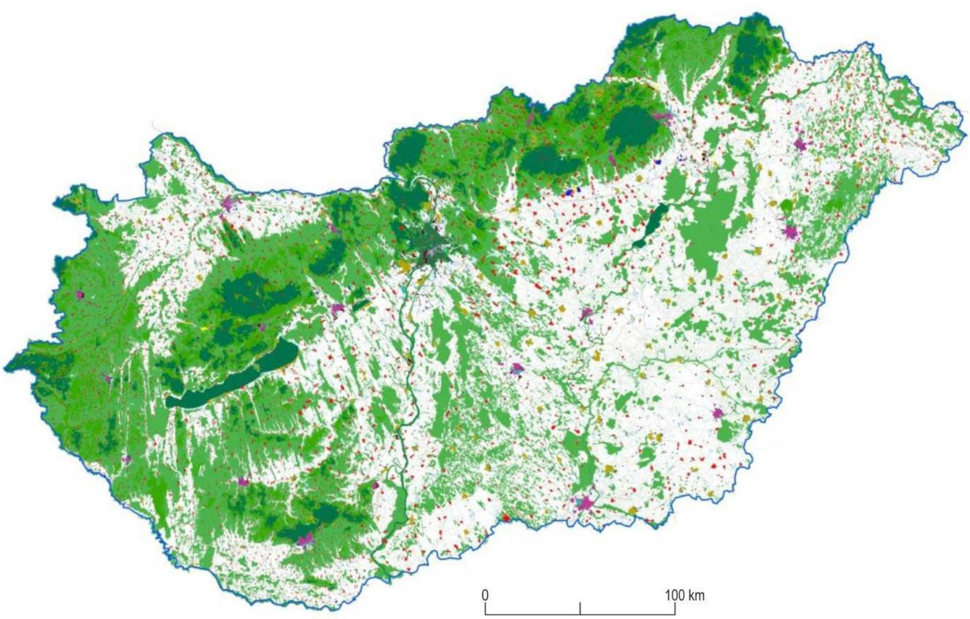

Fig. 8. Aesthetic evaluation of natural (green tones) and artificial (other colors) landscape elements excluding agricultural areas (white)

points including the self-created database of outskirt shopping centres was carried out by the ArcMap operation “mosaic to new raster”.

The artificial linear elements, like roads, highways, railways, power lines were buffered just like watercourses and rasterised. The three layers of artificial landscape elements were created using the Map Algebra function (Figure 7).

Figure 8 shows the map of landscape aesthetics of Hungary evaluating both natural and artificial landscape elements.

11.5 Conclusions

The above assessment of the aesthetic value of the landscape is based on both natural and artificial landscape elements. As already mentioned, the evaluation of the aesthetical value of the landscape depends on the person who is doing the assessment, i.e. it is subjective.

The analysis of natural landscape elements draws our attention to the Hungarian landscapes with outstanding beauty and rich biodiversity. The investigation of natural attraction of landscapes, especially in relation to forests, lakes and varied relief brings about a useful and easily understandable product for the experts of tourism. The complex evaluation of natural and artificial landscape elements provides a good supporting tool for decision making.

The assessment of the aesthetical value of agricultural areas combined with landscape diversity is an important task for the future. The investigation of the relationship between ecosystem services and the aesthetical value of the landscape is aa significant task as well. The study of buffer zones (visibility buffers) will be extended to the bigger rivers (Danube, Tisza). The visual effects of rivers and lakes extends over a large area in their neighborhood and this visual effect together with other landscape elements representing high aesthetical values may identify landscapes with outstanding beauty.

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12. Desertification sensitivity

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12.1 Introduction

The global problem of desertification was discussed in Chapter 1 shortly. As already indicated, Hungary is also threated by desertification. The processes of aridification are already present in the central part of Hungary, i.e. in the Danube-Tisza Interfluve.

In Europe the most significant desertification threat is in the Mediterranean region. The first milestones were the MEDALUS (Mediterranean Land Use and Desertification) I-III projects in the 1990s, including the identification of areas sensitive to desertification. The indicators of desertification and desertification sensitive areas were determined in the DESERTLINK project (Brandt 2003). The Geographical Research Institute of the Hungarian Academy of Sciences, predecessor of Geographical Institute of the Research Centre for Astronomy and Earth Sciences took part in MEDALUS II (EU FW IV, 1994-1996) and III (EU FW IV, 1996-1999) projects with a study area in the Danube-Tisza Interfluve (Kertész et al. 2002). The objectives included also climatological investigations to explore the impact of global climate change on the climate of Hungary. Soil property and vegetation changes were studied in environmentally sensitive areas. Recent groundwater level changes have been monitored and future trends predicted. Soil moisture dynamics in soil profiles and the impacts of groundwater level changes on soil processes were studied.

The depletion of the groundwater reserves is the key issue in the Danube-Tisza Interfluve. A most serious aspect of the aridification trend here is extremely reduced infiltration into the soils and reduced recharge of groundwater. The co-operation of several factors is responsible for decreasing groundwater levels: lower precipitation and high evaporation explain about 50% of the drop, but the extraction of confined groundwater for drinking water supply (25%), afforestation and other land use changes (10%), drainage regulation (7%), direct extraction of free groundwater as well as reduced recharge from the neighboring hills and from the Danube (6%) are also important factors.

During the last three decades studies on desertification became quite fashionable also in Hungary because of the growing importance the topic, first of all due to the growing awareness and threat of climate change. There are significant research projects and publications on the topic (Szalai et al. 2000, Horváth et al. 2005, Kröel et al. 2006, Lellei et al. 2008, Rakonczai et al. 2008, Pongrácz et al. 2009 etc.).

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Publications on the identification of areas sensitive to desertification (Basso et al. 2000, Thornes 2004, Salvati, Bajocco 2011) and on Environmentally Sensitivity Areas (ESAs) and indices (ESAI) discuss the approaches to characterize sensitivity. The ESAI index was applied and validated in Mediterranean Europe under different climatic conditions (see e.g. Basso et al. 2000, Brandt 2005). The method shown in this paper is similar to that of the ESAI establishing land sensitivity to desertification.

The objective of the present study is to investigate desertification sensitivity in the Danube-Tisza Interfluve by applying indices taking various factors into account.

12.2. Methods

Desertification sensitivity is determined by many factors. Izzo et al. (2013) investigated environmentally sensitive areas in the Dominican Republic by identifying areas with different degrees of susceptibility to land degradation and resilience. Critical sensitivity to desertification is first of all the consequence of intense and inadequate land use.

The study area is the meso-region of Danube-Tisza Interfluve with a total area of almost 10 000 km^2 including the administrative area of 104 municipalities. It is a lowland covered by sand, loess and loess-like sediments. The low-lying areas are filled with swamp clay, calcareous silt, peat and meadow limestone. The high lying areas are sand dunes emerging from the sand covered plain (Lóki 1997). The Danube-Tisza Interfluve has a very poor surface water network. The number of sunshine hours is high, mean annual precipitation is low (500-600 mm), droughts occur frequently. As already indicated, the driving force of aridification processes is the fluctuating groundwater level, i.e. groundwater subsidence.

A score system is applied for the identification of the of various sensitivity values of the study area. The method is based on the method of Kosmas et al. (1999). Four factors are included in the sensitivity analysis (Figure 1): (1) soil (soil texture, soil water management, soil organic matter content, salinity); (2) climate (mean annual rainfall (1961-1990), drought index (1961-1990); (3) vegetation (percentage of forests, fire risk); (4) land use intensity. Sensitivity indices were calculated for each factor (sub-)factor. The maps shown in Figure 1 are compiled on the basis of the sensitivity categories determined for each factor. Four classes were created: critical, sensitive and potentially sensitive areas as well as the areas not sensitive to desertification (Kertész, Őrsi 2013, Kertész et al. 2015).

The sensitivity of each contributing (sub) factor was determined first (e.g. soil texture, soil water management etc.). The sensitivity value of each factor (e.g. soil) was then calculated as the geometric mean of the sensitivity values of the contributing (sub) factors. Scores between 1 and 2 were given to each sub-factor and factor according to the sensitivity to desertification.

The data were imported form the AGROTOPO database for soils (RISSAC 1991), rainfall data from Dövényi (2010), vegetation data from the CORINE database (Büttner et al. 2003). The Pálfai Drought Index (PDI) is calculated as follows:

$$\text{PDI} = 100 \times \text{April-August mean temperature} / \text{October-August weighted precipitation},$$

where precipitation is weighted according to the water demand of plants in each month (Pálfai et al. 1999). The index was available for 14 meteorological stations (Pálfai et al. 1999), these were interpolated by krieging. The sensitivity of the vegetation was calculated on the basis of fire risk classification of the micro regions (VATI 2005). The forest area

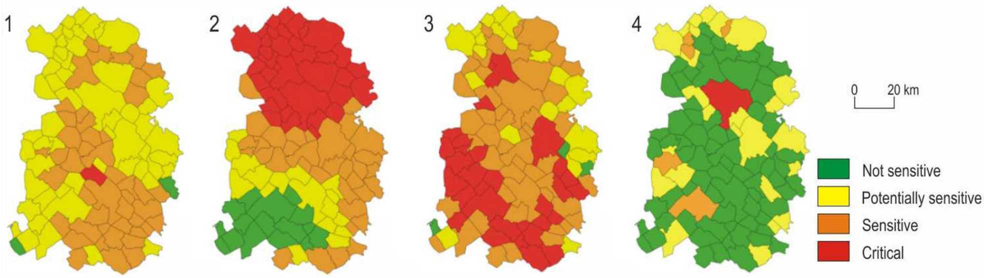

Fig. 1. Soil (Map 1), climate (Map 2), vegetation (Map 3) and management sensitivity (Map 4) from the aspect of desertification in the Danube-Tisza Interfluve

was considered particularly sensitive because of the contribution of forests to groundwater level decline. The intensity of land use was determined by the total amount of water use per unit area (Németh 2010).

12.3 Results

(a) Soil sensitivity is determined by soil parent material which is sand which is sand on the major part of the area. Sand is highly sensitive. Other surface covering sediments are sandy loam, loam and some clay. Soil texture and soil water management properties are generally promoting desertification. In the western part of the area the organic matter content is low. Saline soils occur mainly in the low-lying spots in the SE. The general statement is that soil properties are in favour of desertification, first of all on the sand ridges in the central part. Loess covered areas along the rivers are less sensitive.

(b) Climate sensitivity. The most sensitive area is the northern part. The highest drought index values are in the NW. They gradually decrease towards the SW where the yearly average of precipitation is the lowest.

(c) Vegetation sensitivity. Forest cover is the highest in those areas where soil conditions are the worst. Forests were planted to stabilize the sand dunes. The problem is that the forest uses a lot of groundwater contributing to groundwater subsidence. Forest fire risk is the highest in the southern part and the lowest in the northern part as well as near the Tisza river. The most sensitive territory is the south-western part of the area is, due to the high fire risk and to the high percentage of forests.

(d) Land use intensity. Water consumption is the highest in the major cities (Kecskemét, Kiskőrös) and in the settlements with the smallest administrative area. It is relatively high in the surroundings of Kecskemét and Budapest in the north. Apart from the large settlements and their neighbourhood the spatial distribution of this factor is the opposite of the soil quality index because the areas with the worst soil conditions were afforested

(e) Sensitivity to desertification. The north-western and south-eastern parts of the study area are the most sensitive to desertification. The drier climate and by the high density of forests explains this situation in the NW.

In the SE the poor quality of the soil, the high risk of forest fires and the drier climate are the reasons for high sensitivity.

Figure 2 consists of two maps. Map No. 1 was prepared so that only the sensitivity of soil, climate and vegetation are taken into account and land use intensity is neglected. On this map sensitivity is not so high near Kecskemét which is the largest city. Map No. 2 was prepared by taking land use intensity into account as well.

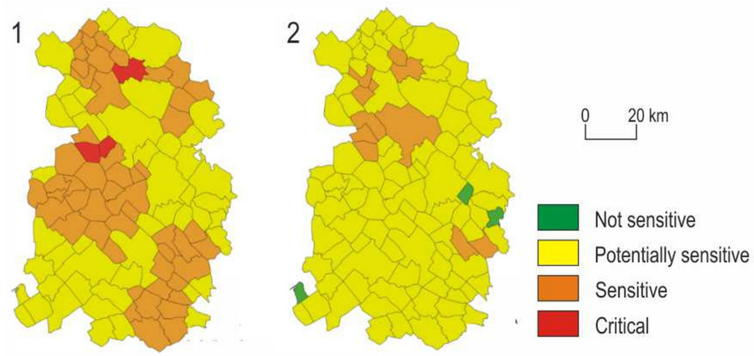

Fig. 2. Desertification sensitivity indices in the Danube-Tisza Interfluve due to natural factors (Map 1), and taking land use intensity into account (Map 2)

12.4 Conclusions

The method presented in this paper proved to be well applicable for the characterisation and mapping of landscape sensitivity.

The results and the maps were validated, they are in accordance with the present situation in the study areas. Desertification is an important issue also in Europe, especially in the Mediterranean region. The central part of Hungary is also affected by desertification. The method presented above is a well applicable tool to identify the areas with different degrees of sensitivity and delineates the areas where the situation is already critical.

On the basis of future climate change scenarios desertification risk will grow, the areas already affected by this process are supposed to extend. Temperature increase and precipitation decrease accompanied with more frequent and longer periods of drought call for a policy making strategy to combat desertification.

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THEORY – METHODS – PRACTICE 74.

In the recent past, especially in this century human society has been utilizing and even exploiting natural resources and ecosystem services, offered by various landscapes in a more intensive way than ever. The overexploitation of landscapes leads to landscape degradation. Landscape degradation is one of the most urging problems of the Globe today with an ever-growing importance. According to various estimations, 20–75% of global land area is presumably already degraded. The consequence is a persistent decline in land productivity and of the provision of other ecosystem services.

This book gives an overview of landscape degradation in Hungary and contains also research results of Project No. 108 755 of the National Research, Development and Innovation Office (NKFIH), entitled: “Analysis of the natural micro-regions of Hungary from the aspect of landscape degradation.” This study was supported by NKFIH and this support is gratefully acknowledged here.

Altogether twelve degradation processes are dealt with: (1) sheet erosion, (2) gully erosion, (3) wind erosion, (4) mass movements, (5) soil sealing, (6) landscape aesthetics, (7) salinization, (8) acidification, (9) wounds in the landscape, (10) physical degradation, (11) desertification, (12) degradation of waters. The areal distribution of the degradation processes is presented on maps as well.

In addition to the survey of landscape degradation processes acting in the country, an analysis of degradation sensitivity is provided. The expected results have not only theoretical but also practical relevance for policy makers at local, regional and country level.

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